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Sato

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(54) FILTER DEVICE

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(22) Filed: **Nov. 4, 2020**

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(51) **Int. Cl.**

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H03H 9/145	(2006.01)
H03H 9/25	(2006.01)
H01P 1/20	(2006.01)
H03H 9/02	(2006.01)

(52) **U.S. Cl.**
CPC ***H01P 1/20*** (2013.01); ***H03H 9/02543*** (2013.01); ***H03H 9/14582*** (2013.01); ***H03H 9/25*** (2013.01); ***H03H 9/6406*** (2013.01); ***H03H 9/6483*** (2013.01)

(58) **Field of Classification Search**
CPC H03H 9/02; H03H 9/25; H03H 9/64
See application file for complete search history.

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(57) **ABSTRACT**

A filter device includes a first filter connected between a common terminal and a first individual terminal, and a second filter connected between the common terminal and a second individual terminal. A pass band of the second filter is in a frequency range lower than a pass band of the first filter. The first filter includes SAW resonators, at least one of which includes divided resonators connected in parallel with each other. Each of the divided resonators includes an IDT. A pitch of the IDT of one of the divided resonators is different from that of another of the divided resonators.

20 Claims, 16 Drawing Sheets

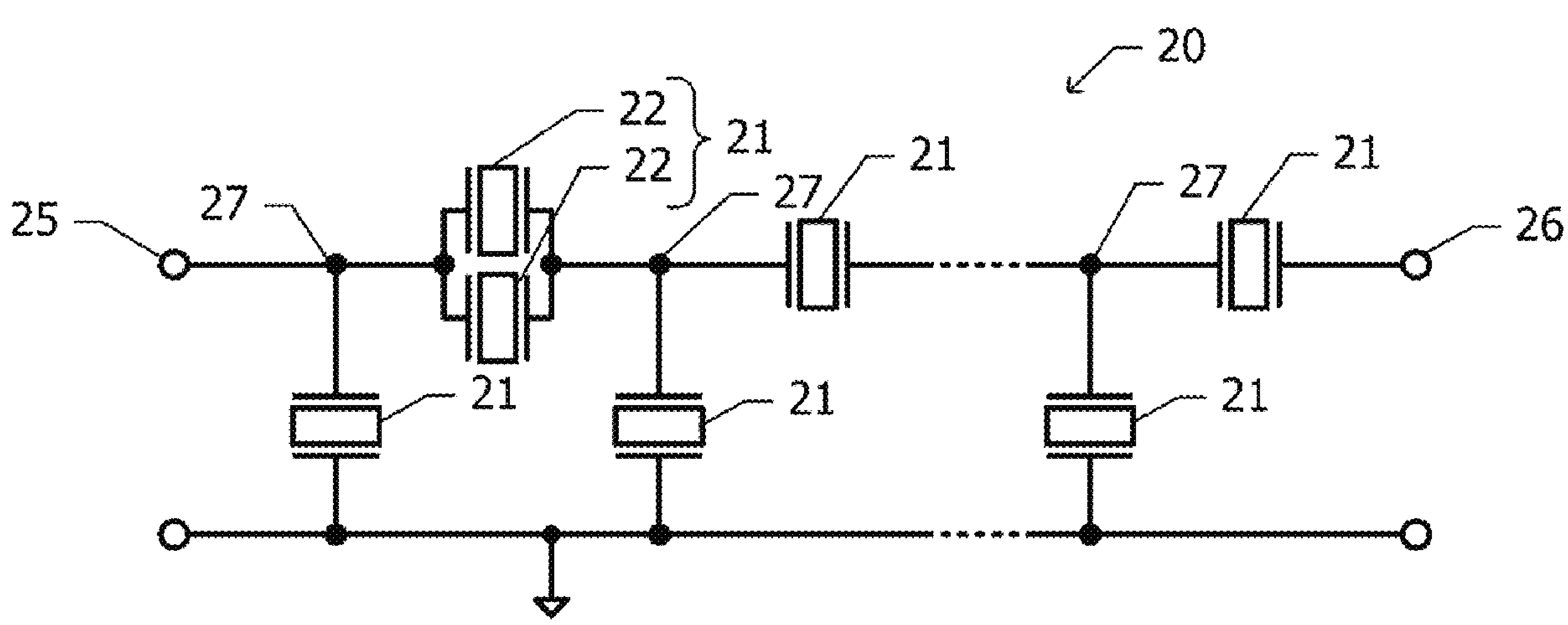

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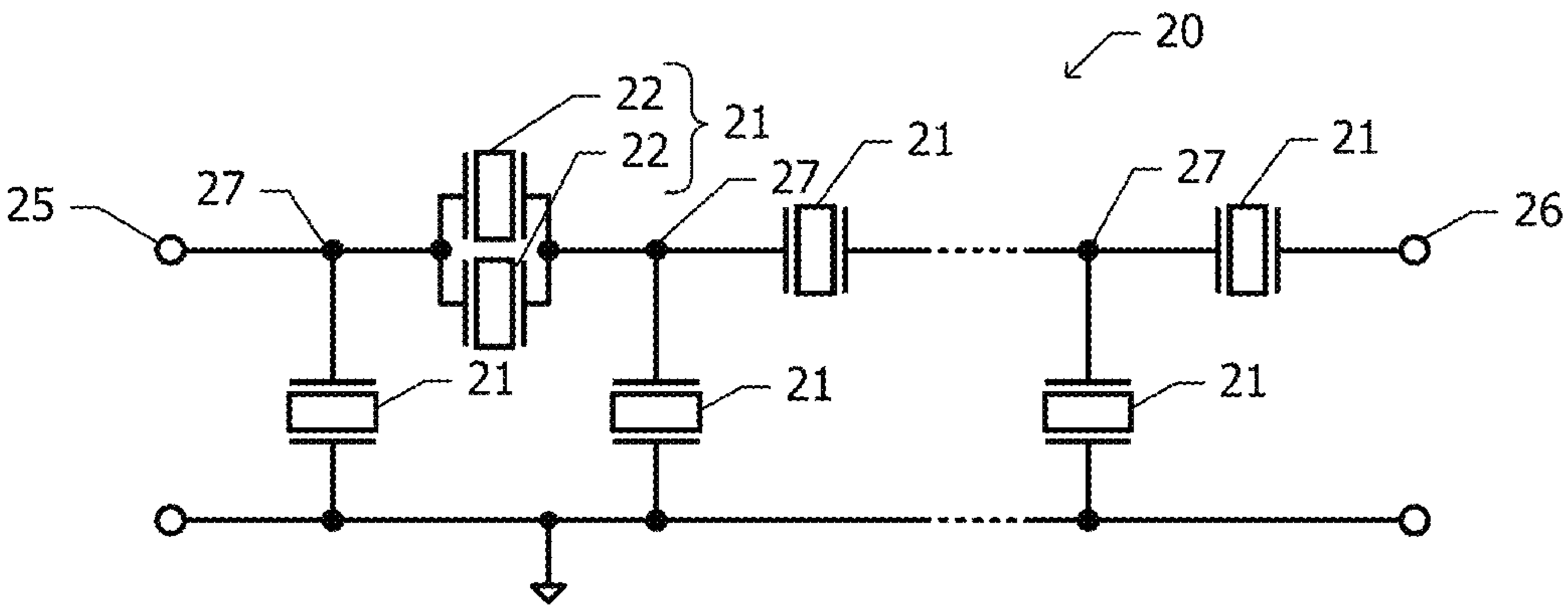
FIG. 1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22
22
21
25
27
27
21
27
21
26
21
21
21

FIG. 2

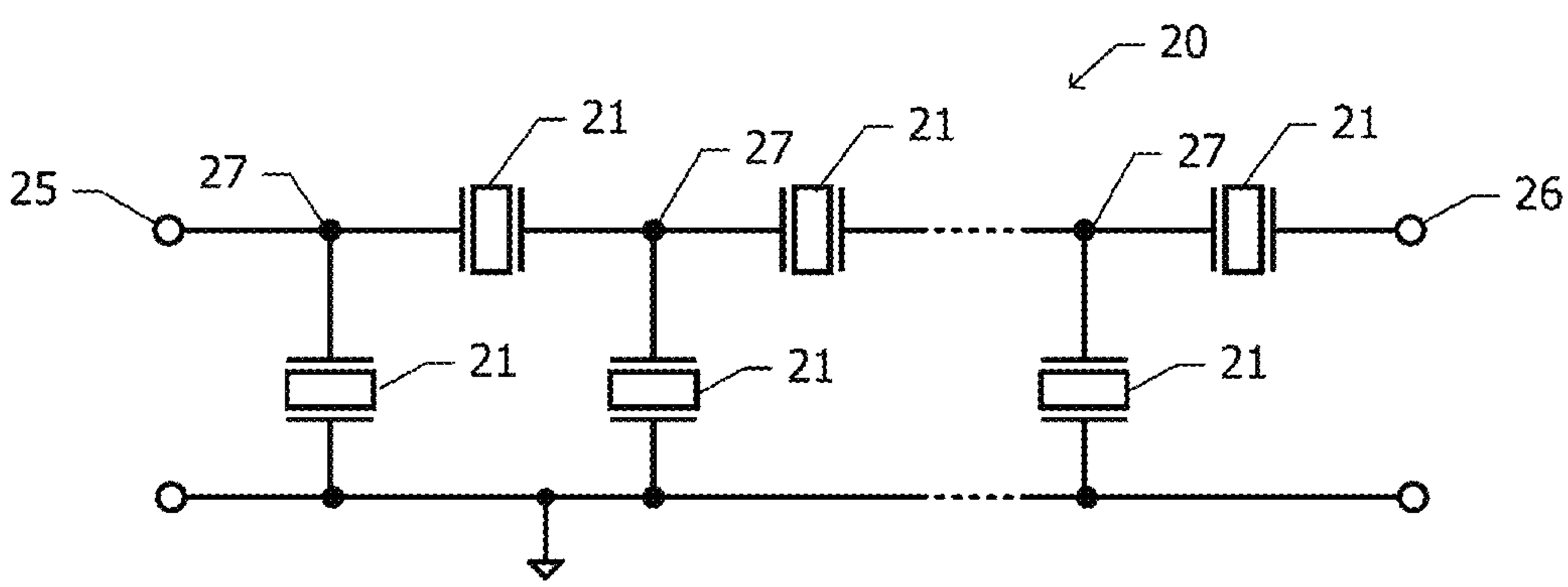

20
21
27
21
27
21
25
27
26
21
21
21

FIG. 3A

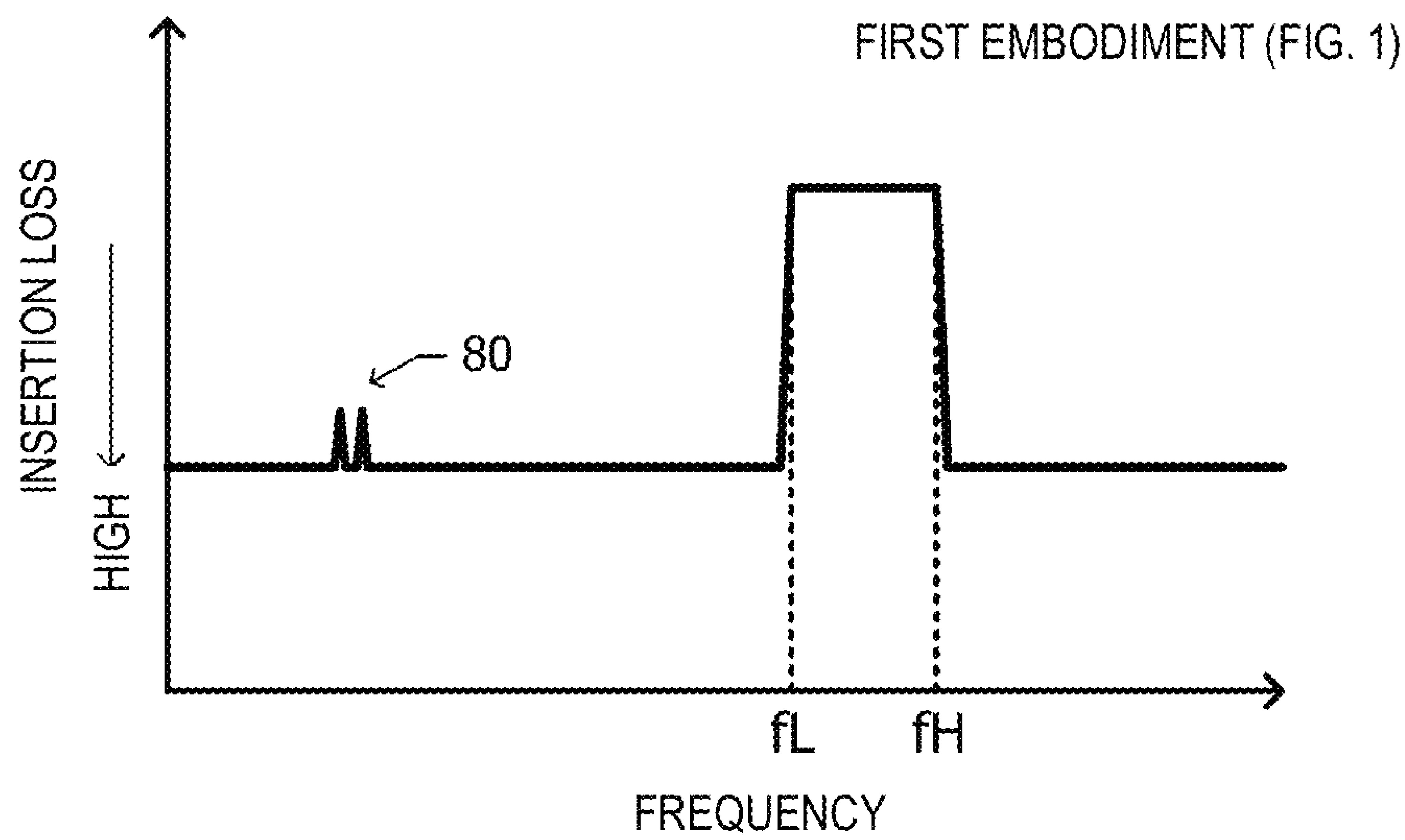

FIRST EMBODIMENT (FIG. 1)
INSERTION LOSS
HIGH
80
fL
fH
FREQUENCY

FIG. 3B

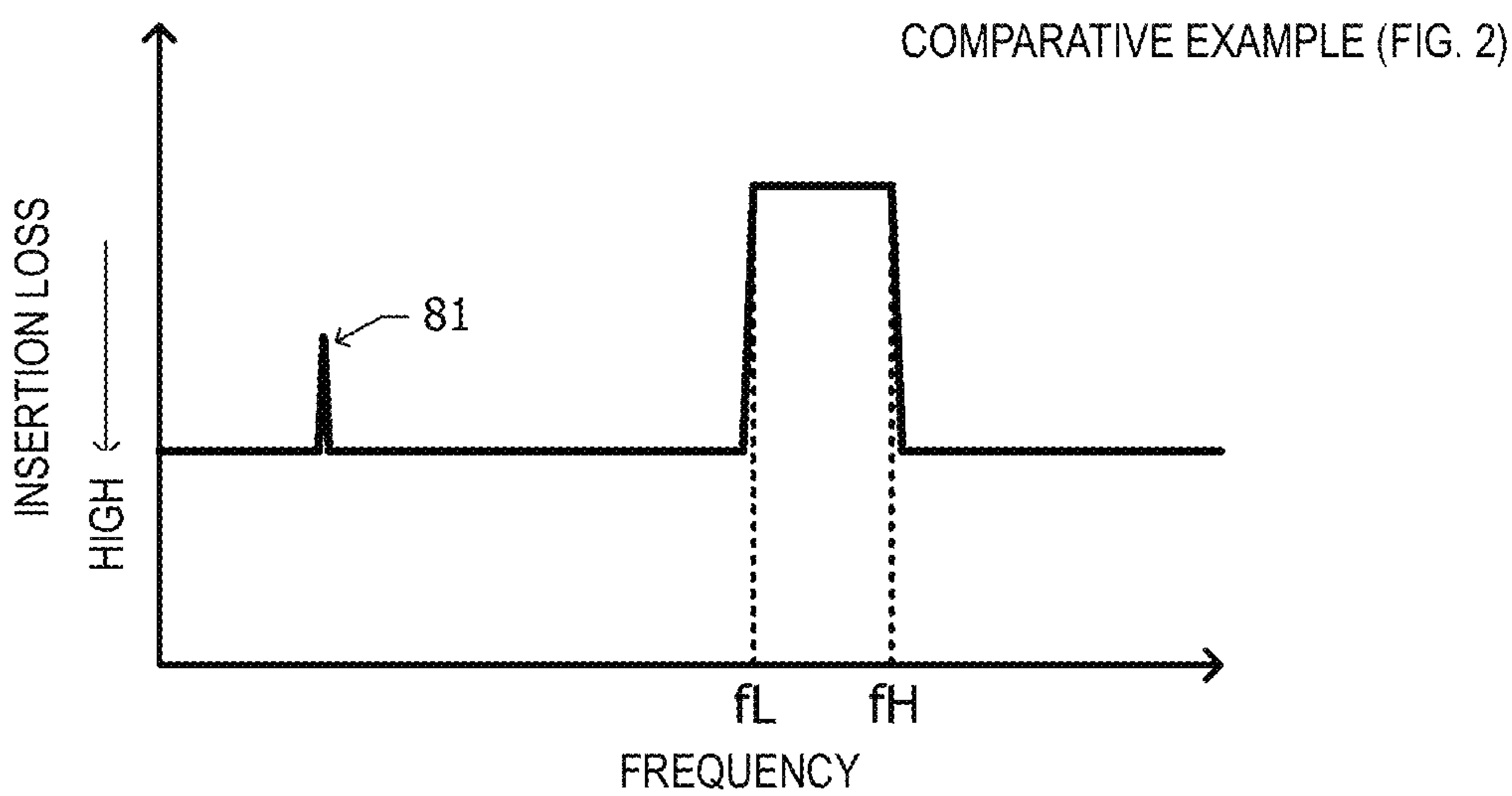

COMPARATIVE EXAMPLE (FIG. 2)
INSERTION LOSS
HIGH
81
fL
fH
FREQUENCY

FIG. 4A

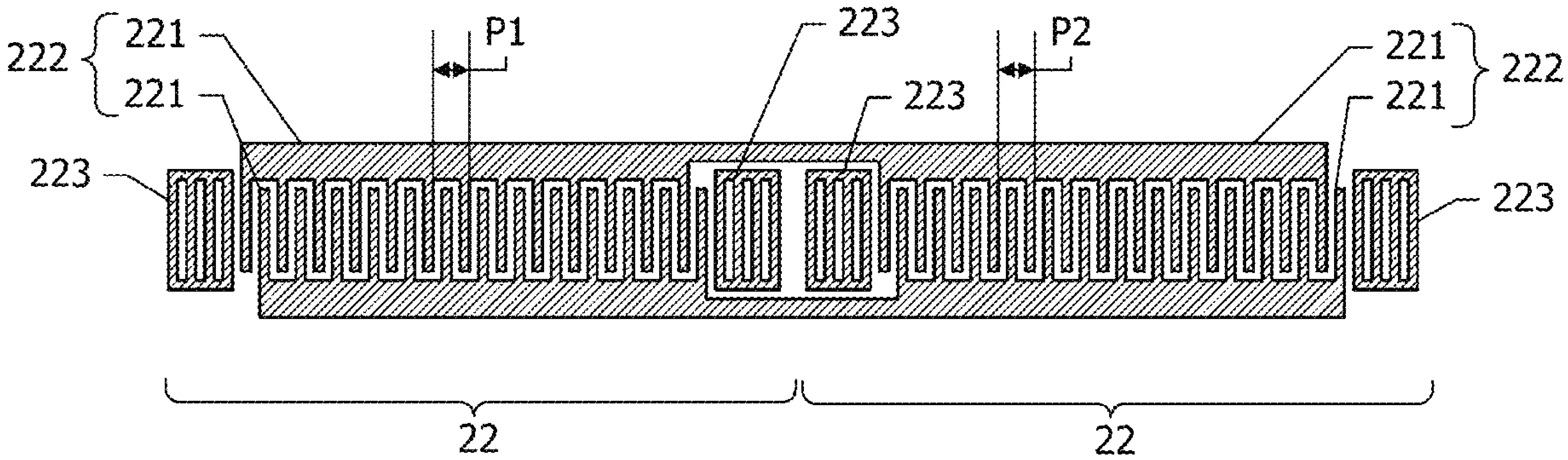

222
221
221
P1
223
223
P2
221
221
222
223
223
22
22

FIG. 4B

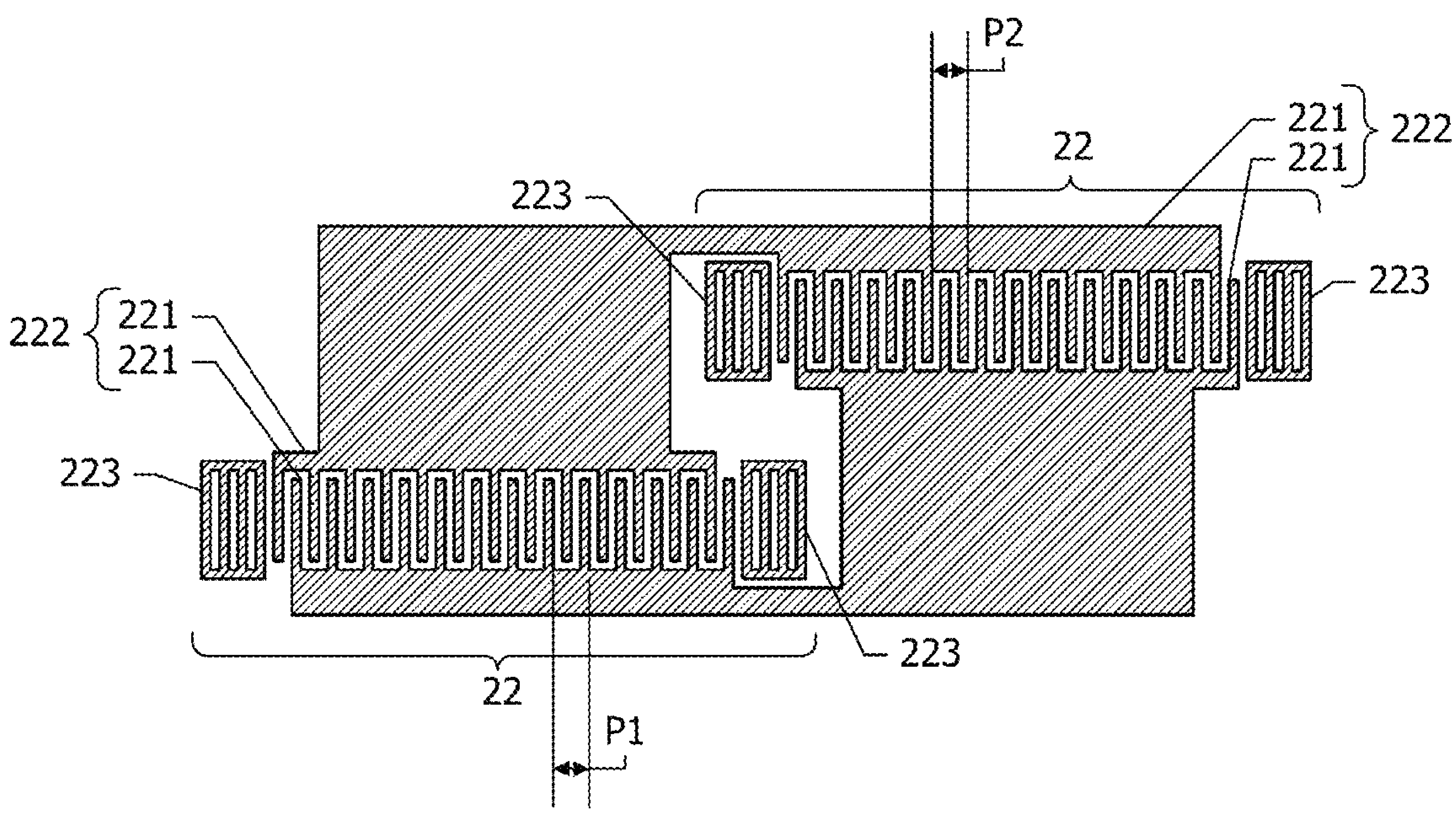
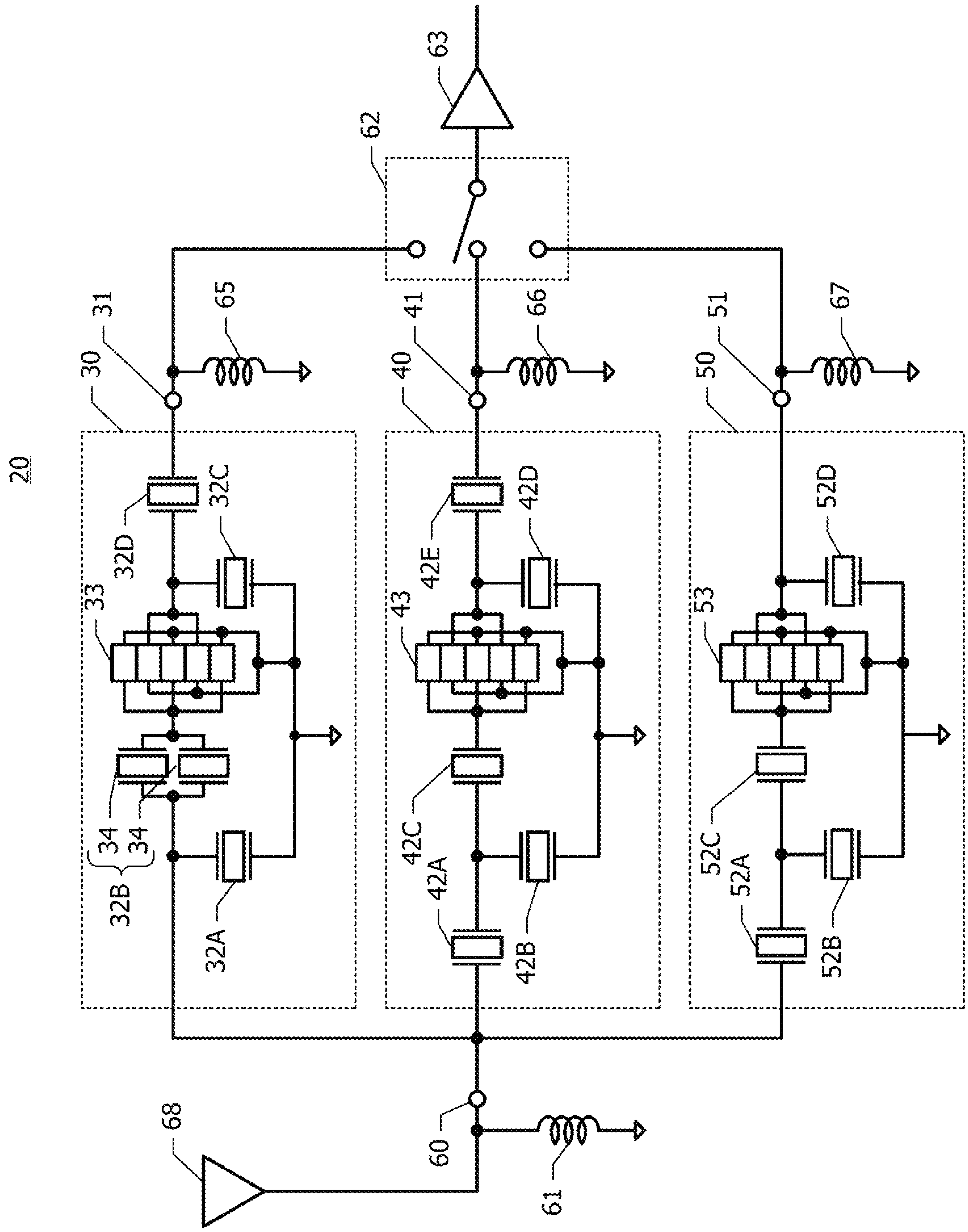

P2
221
221
222
22
223
222
221
221
223
223
223
22
P1

FIG. 5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30
31
32A
32B
32C
32D
33
34
34
40
41
42A
42B
42C
42D
42E
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52A
52B
52C
52D
53
60
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62
63
65
66
67
68

FIG. 6

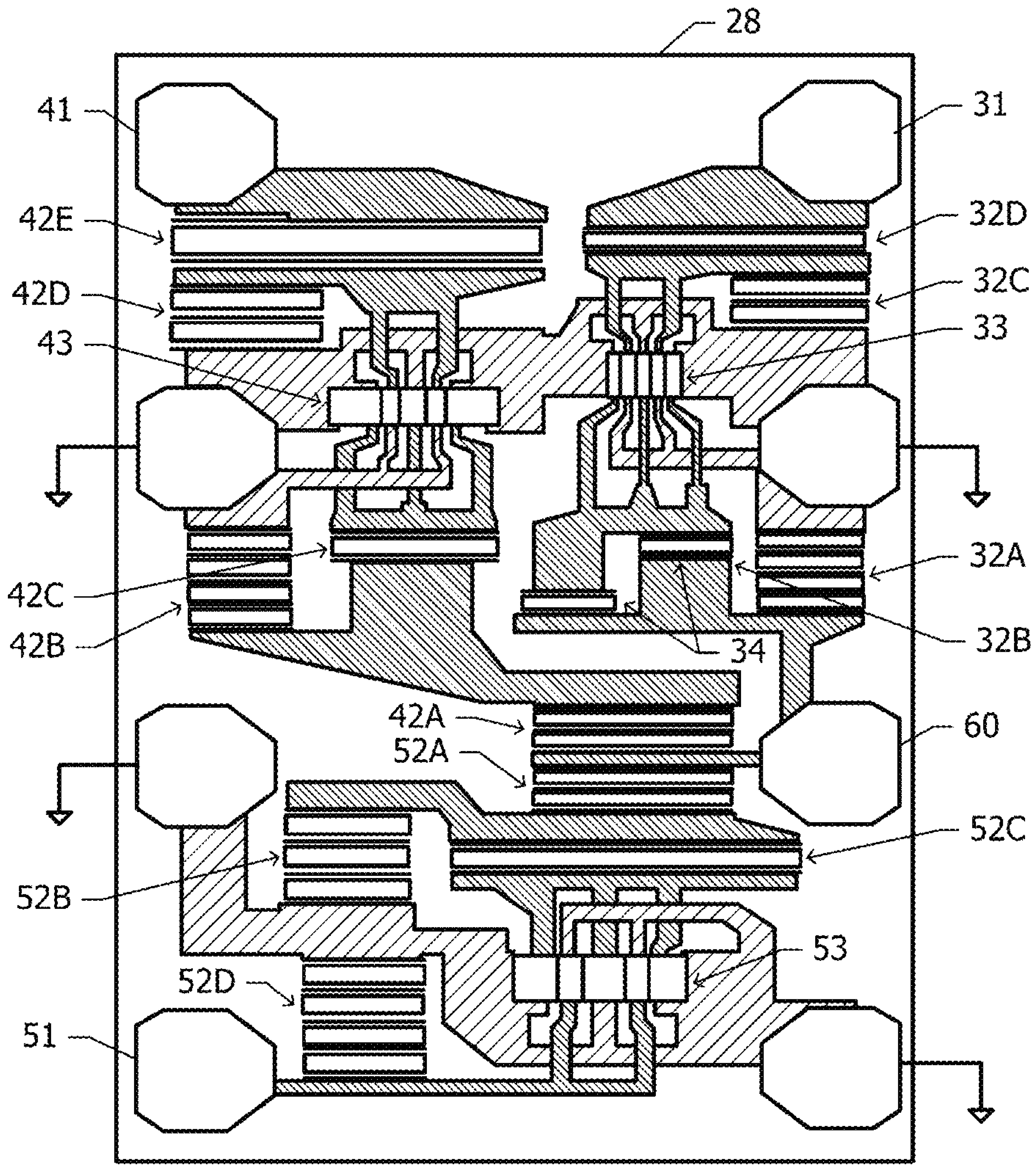
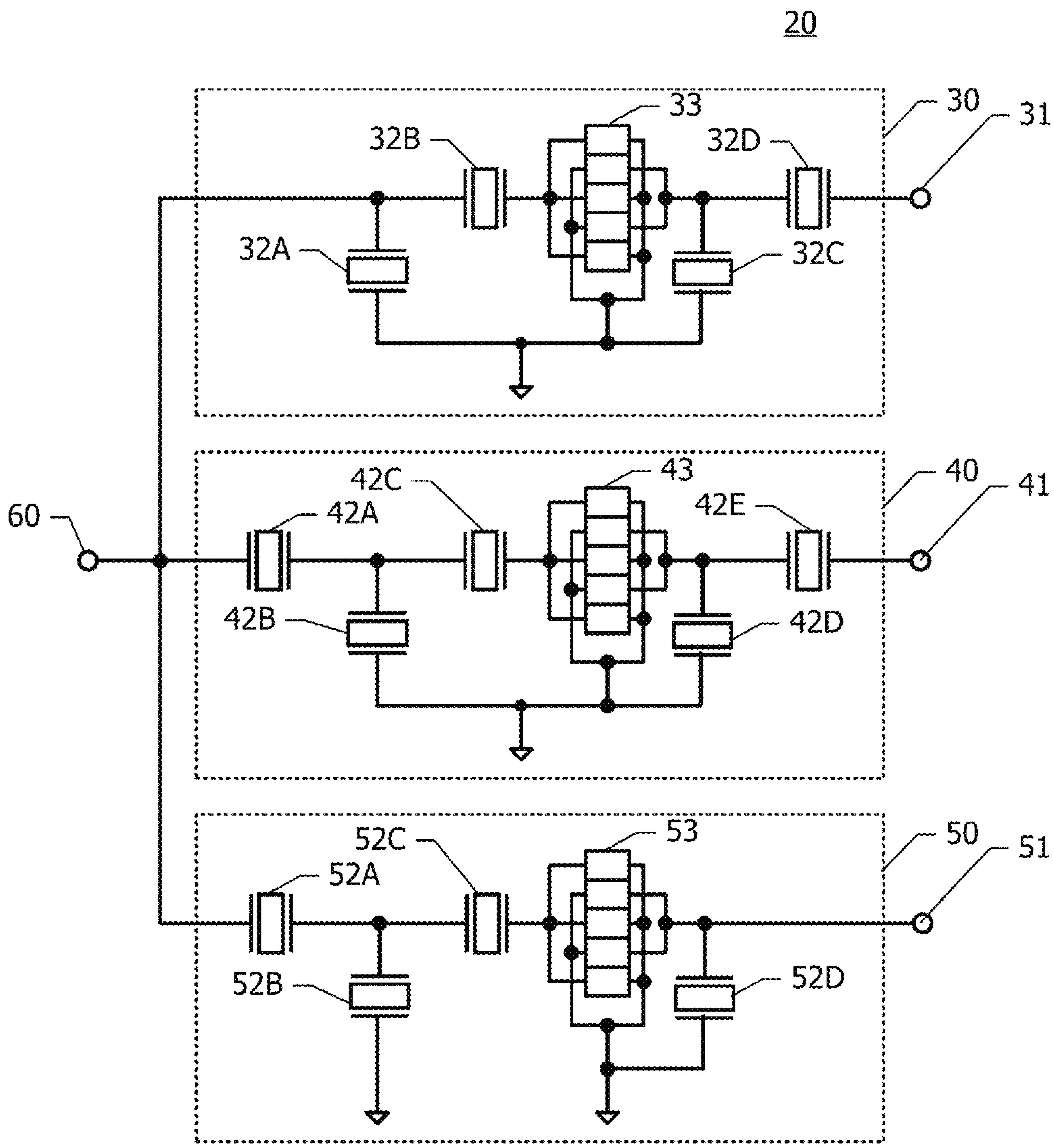

28
41
31
42E
32D
42D
32C
43
33
42C
32A
42B
34
32B
42A
52A
60
52C
52B
53
52D
51

FIG. 7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30
31
33
32B
32D
32A
32C
40
41
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42C
42A
42E
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42B
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53
52C
52A
52B
52D

Fig.8A

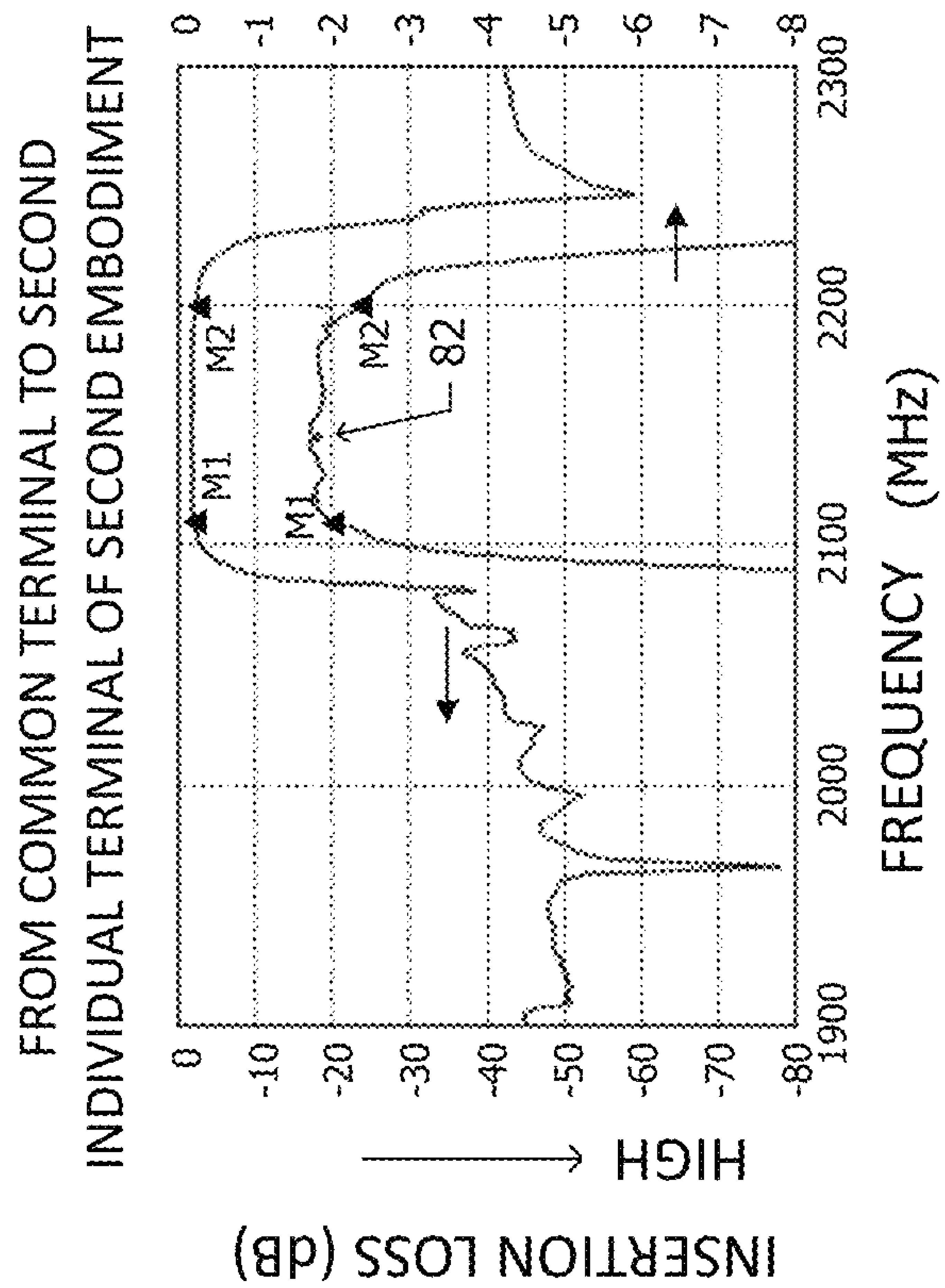


Fig.8B

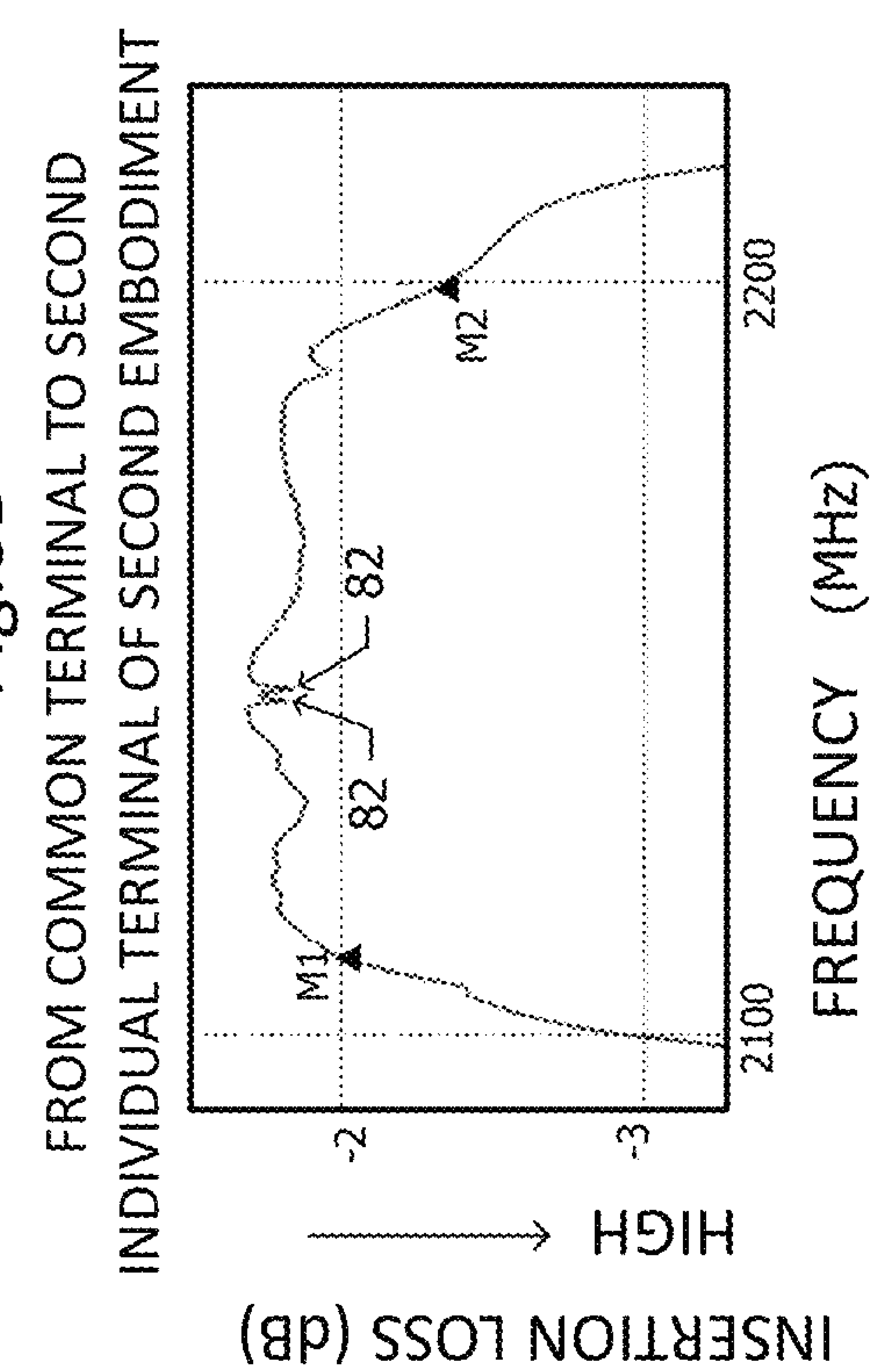


Fig.8C

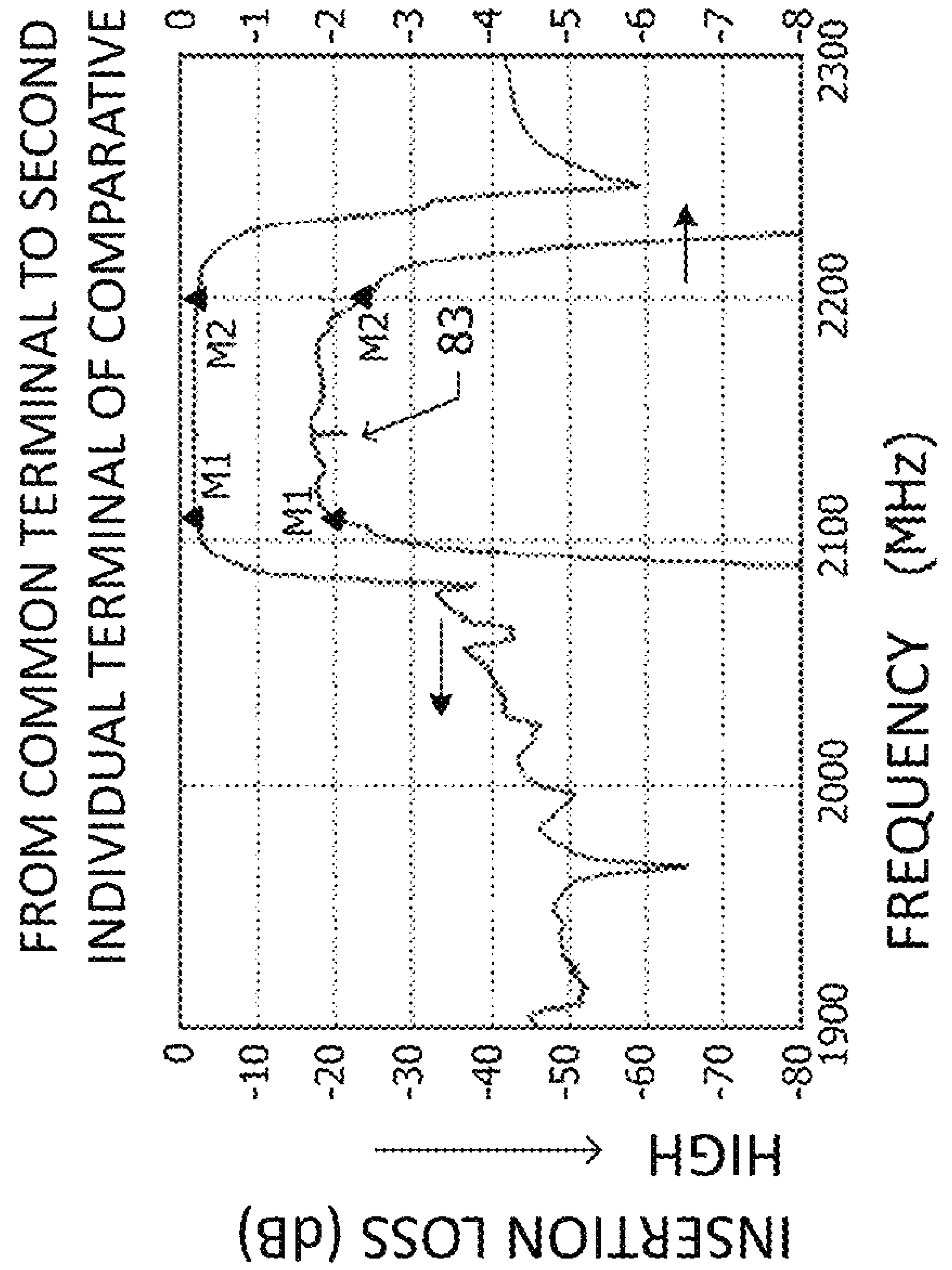


Fig.8D

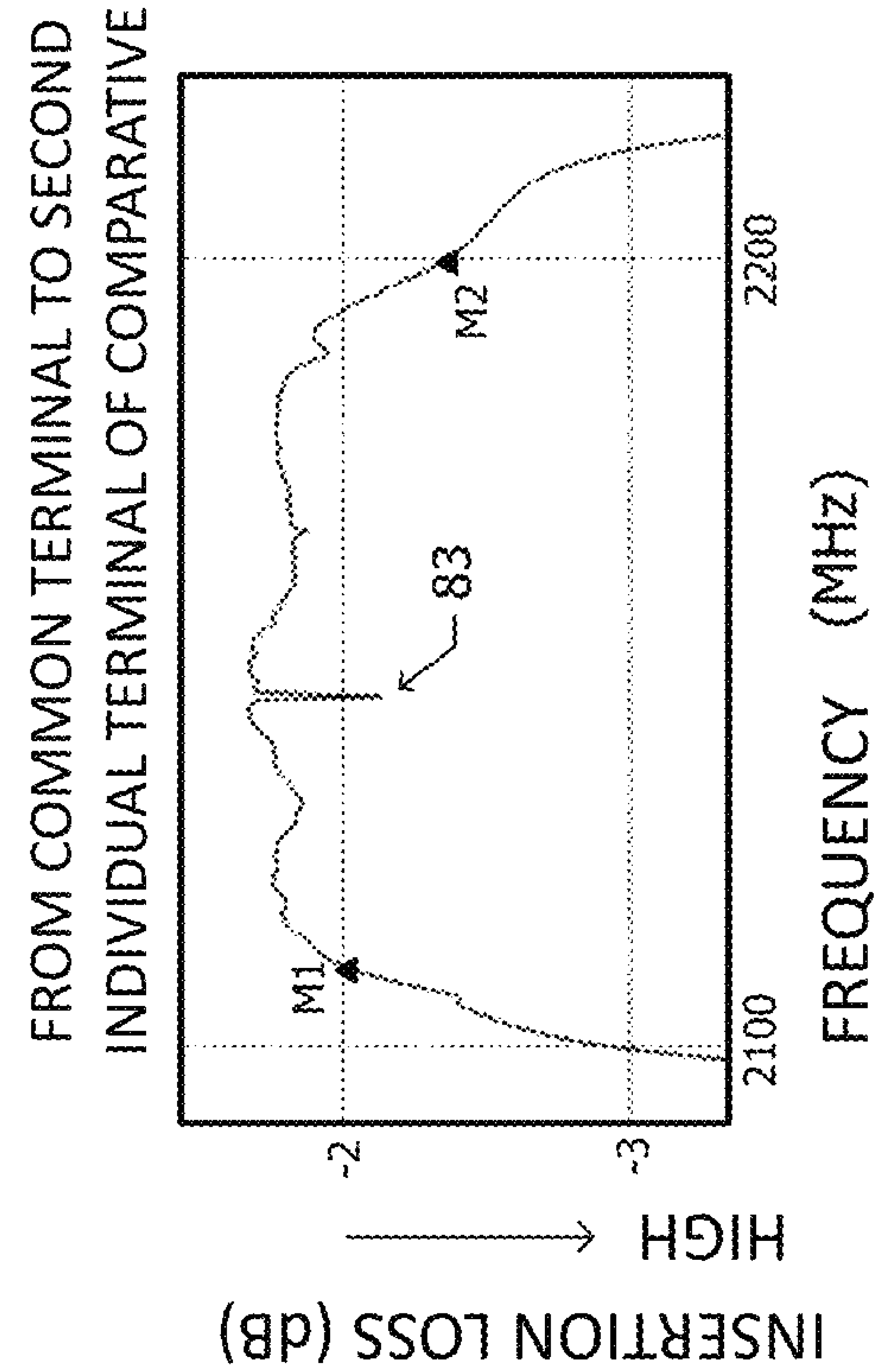


FIG. 9

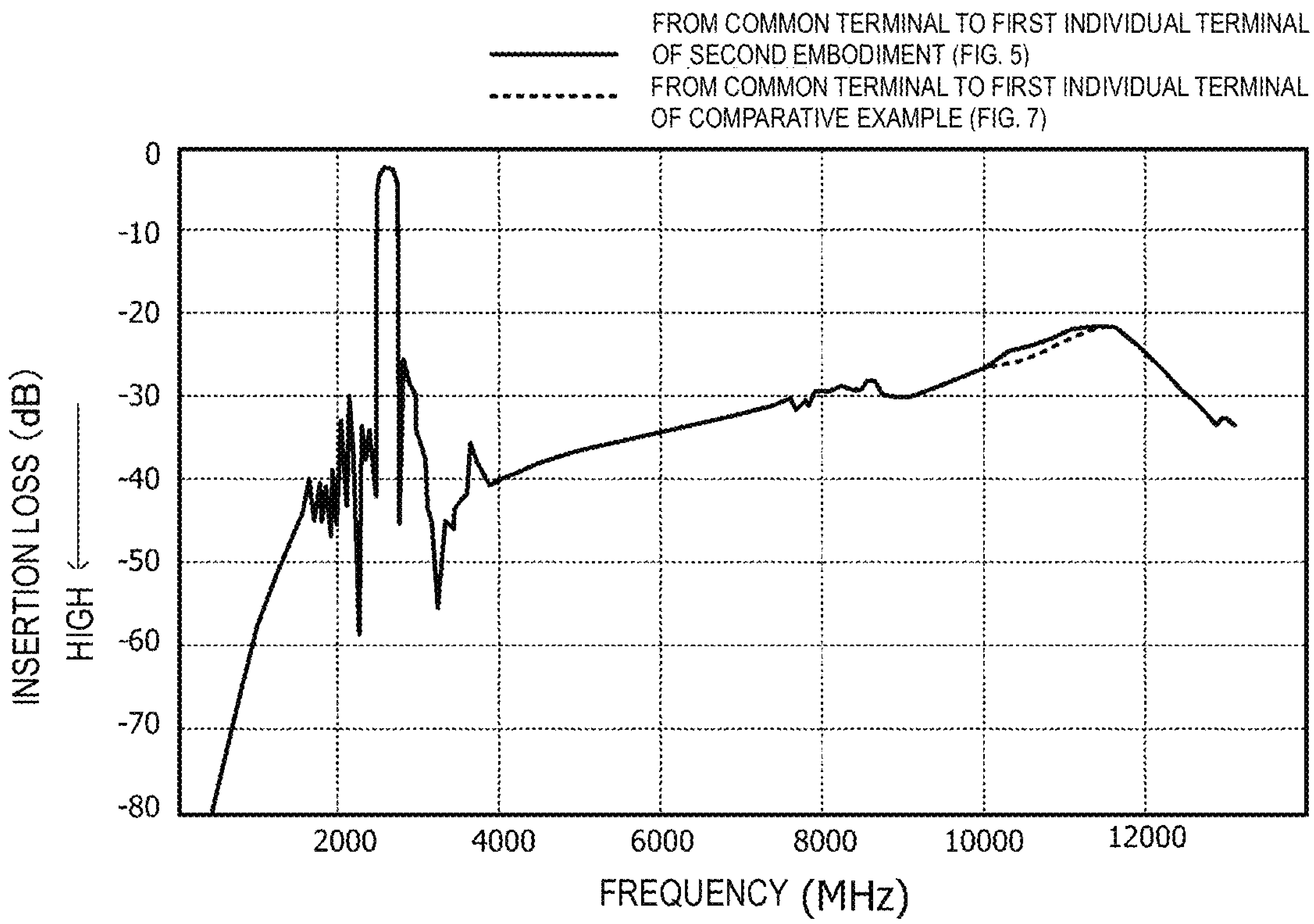

FROM COMMON TERMINAL TO FIRST INDIVIDUAL TERMINAL OF SECOND EMBODIMENT (FIG. 5)
FROM COMMON TERMINAL TO FIRST INDIVIDUAL TERMINAL OF COMPARATIVE EXAMPLE (FIG. 7)
0
-10
-20
-30
-40
-50
-60
-70
-80
INSERTION LOSS (dB)
HIGH ←
2000
4000
6000
8000
10000
12000
FREQUENCY (MHz)

FIG. 10A

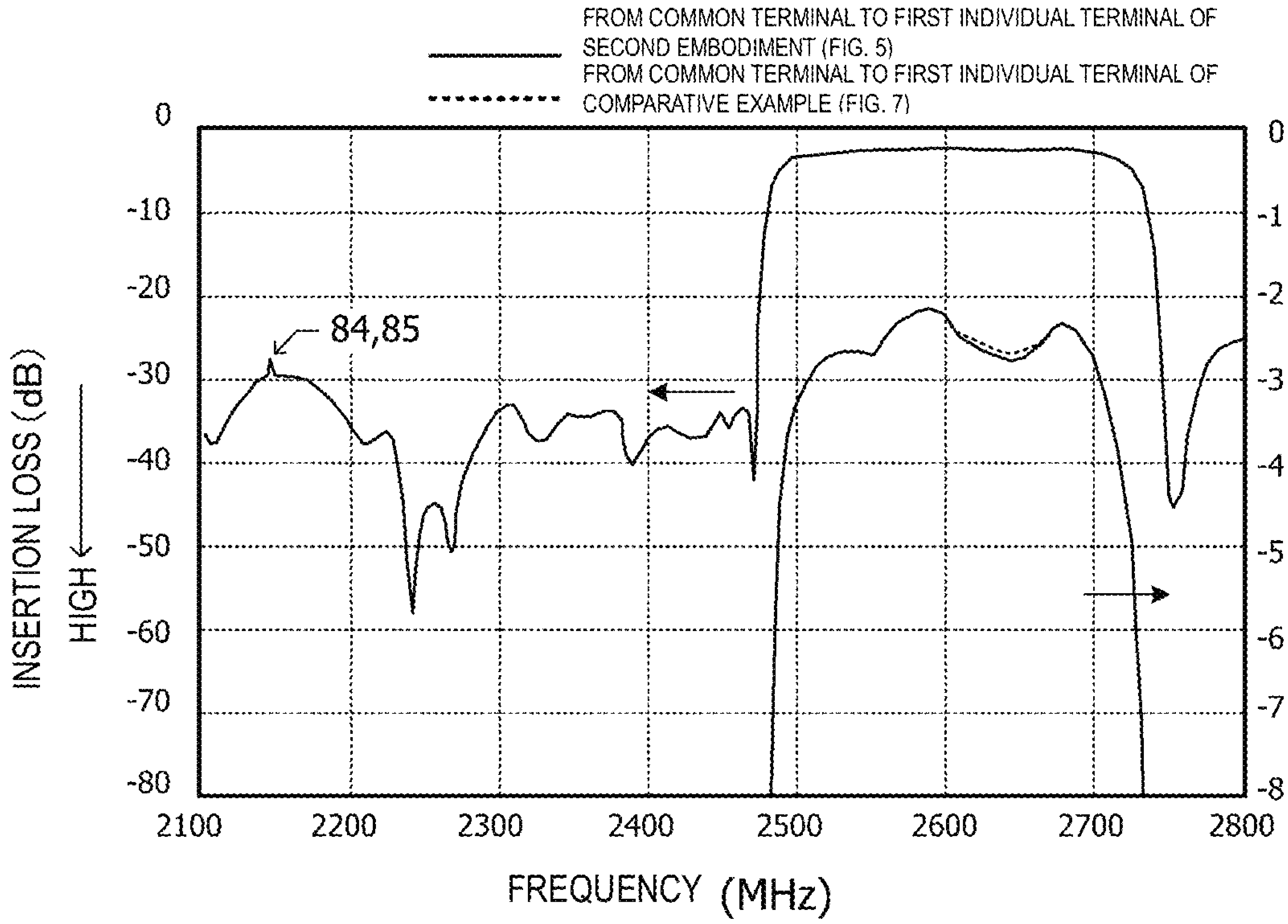


FIG. 10B

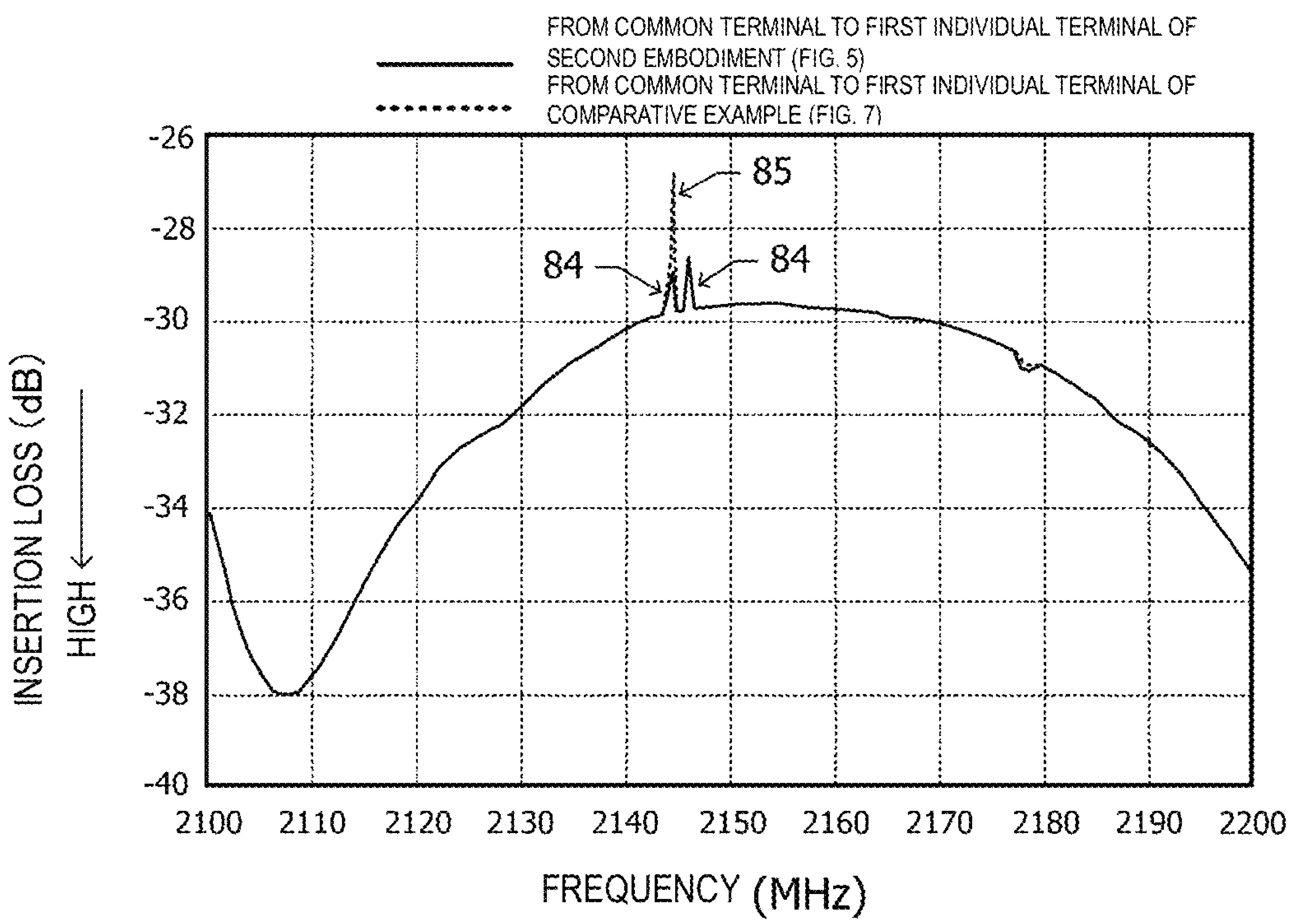
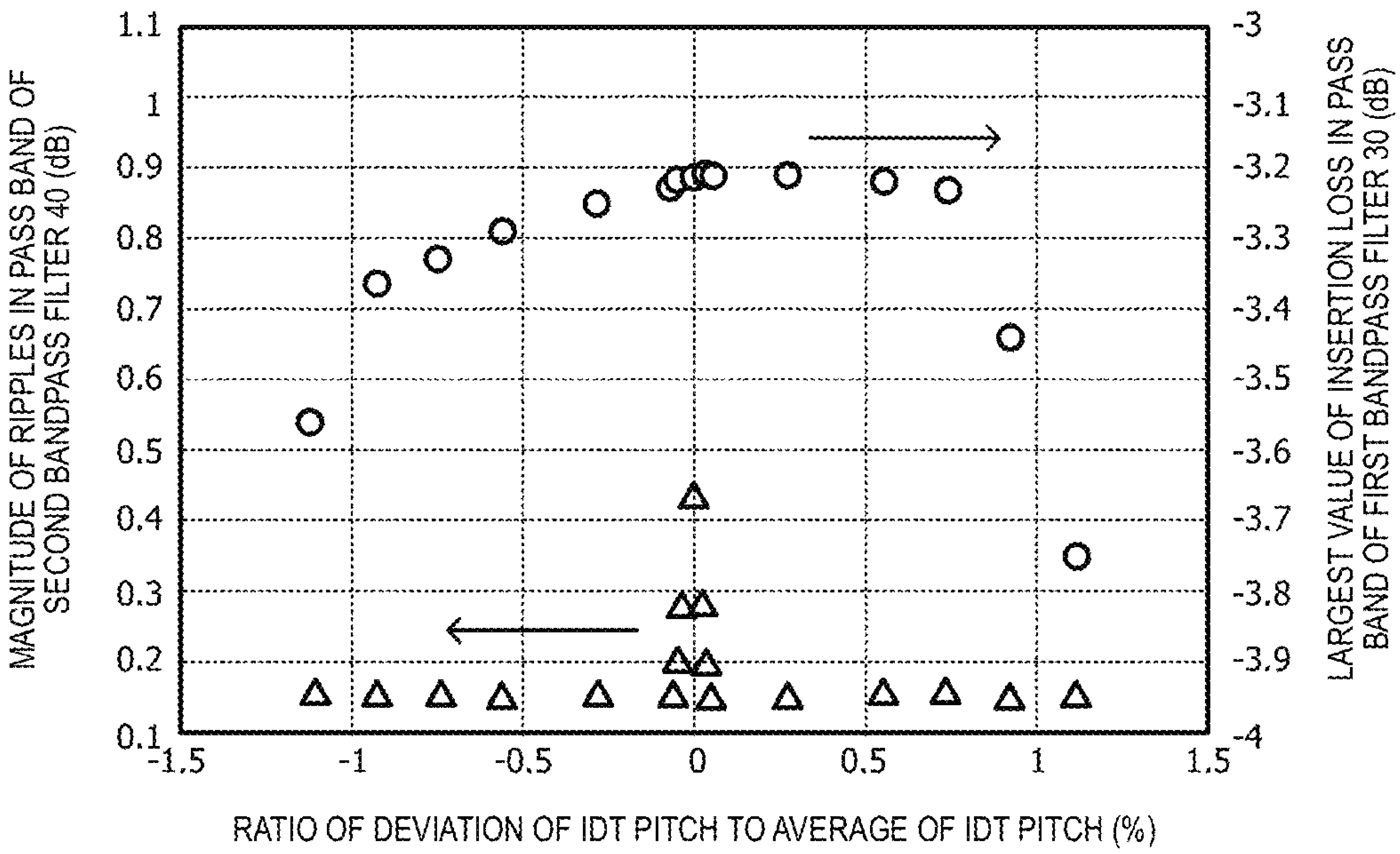


FIG. 11



MAGNITUDE OF RIPPLES IN PASS BAND OF SECOND BANDPASS FILTER 40 (dB)
LARGEST VALUE OF INSERTION LOSS IN PASS BAND OF FIRST BANDPASS FILTER 30 (dB)
RATIO OF DEVIATION OF IDT PITCH TO AVERAGE OF IDT PITCH (%)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-3
-3.1
-3.2
-3.3
-3.4
-3.5
-3.6
-3.7
-3.8
-3.9
-4
-1.5
-1
-0.5
0
0.5
1
1.5

FIG. 12

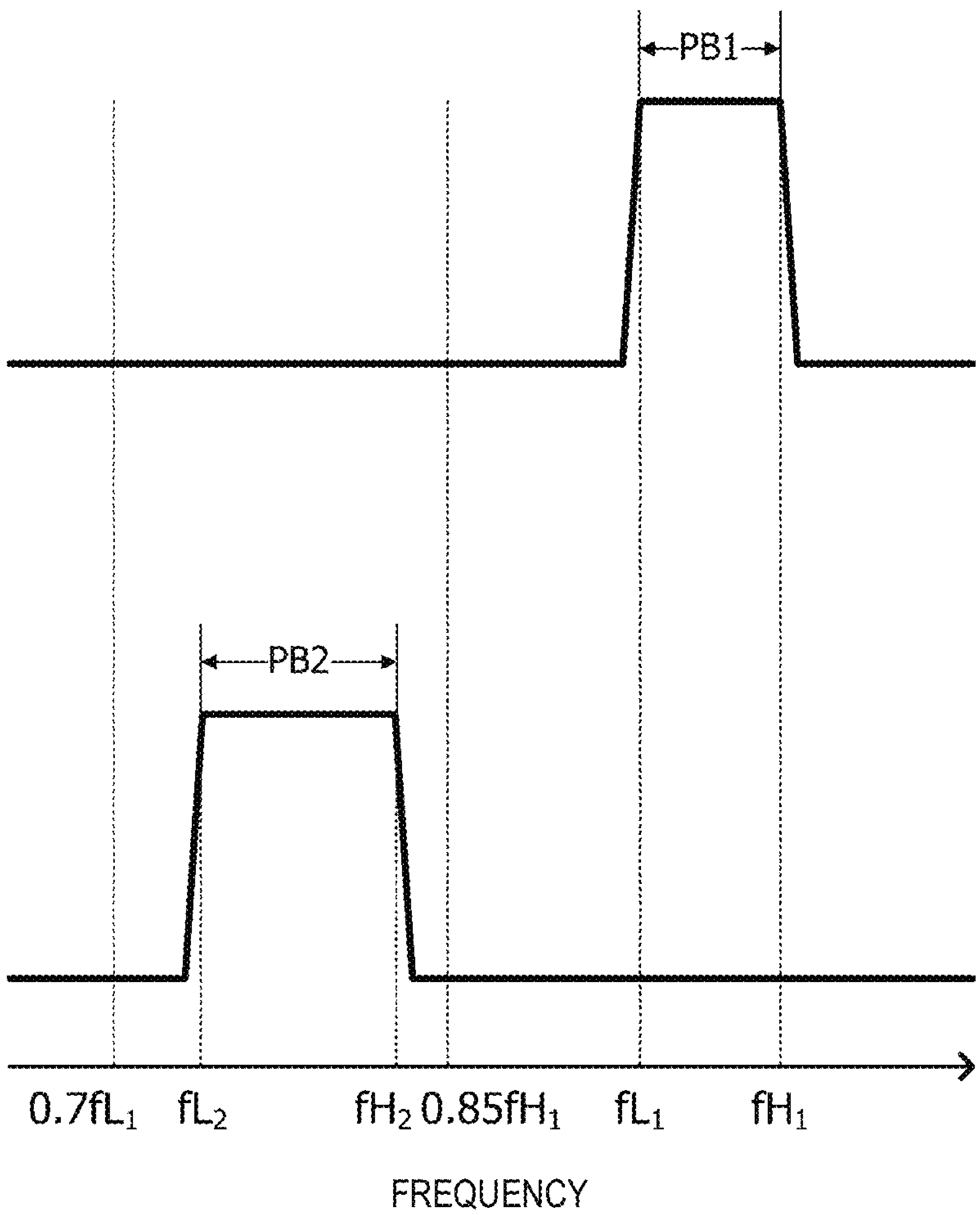


FIG. 13A

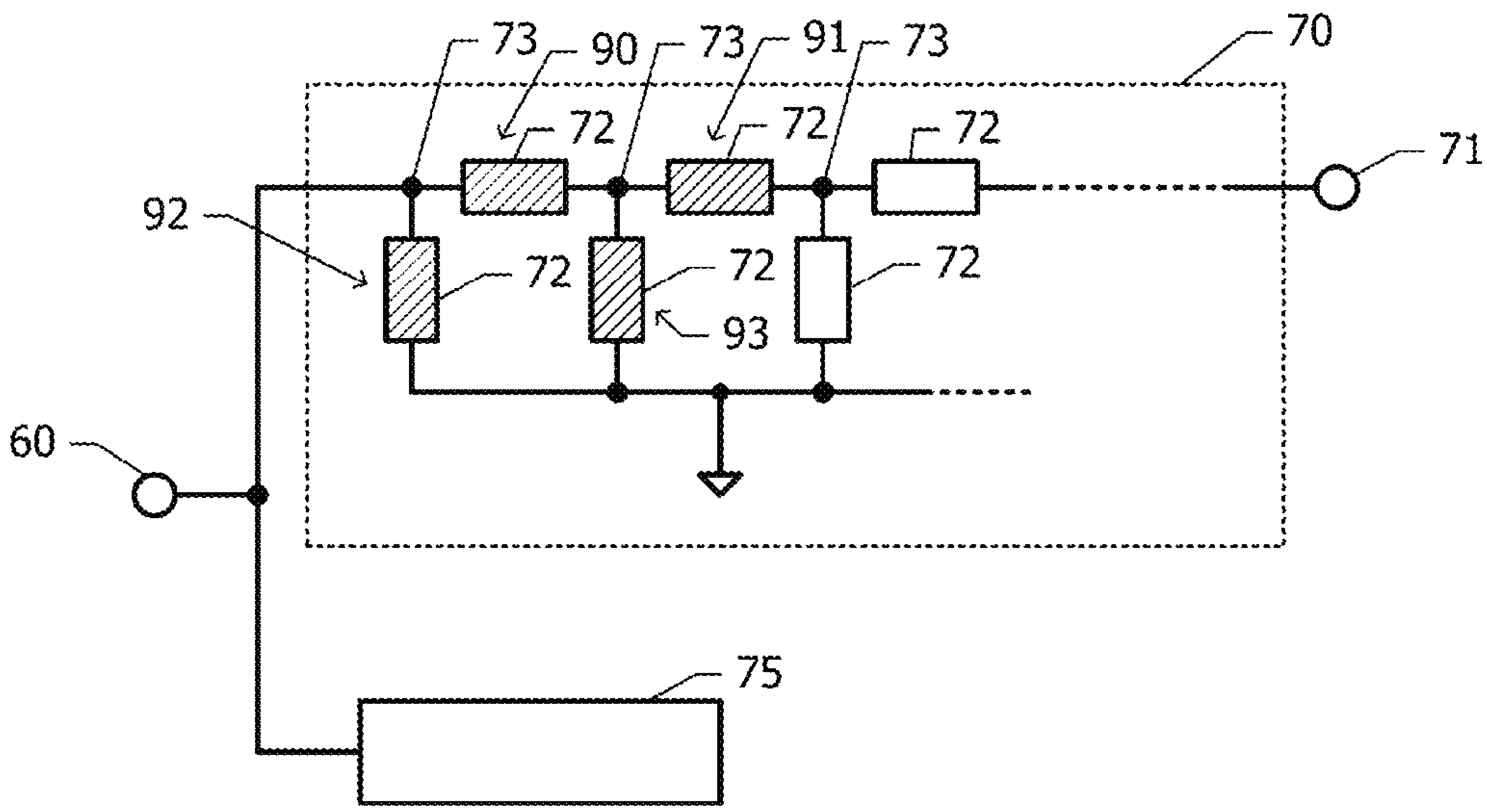


FIG. 13B

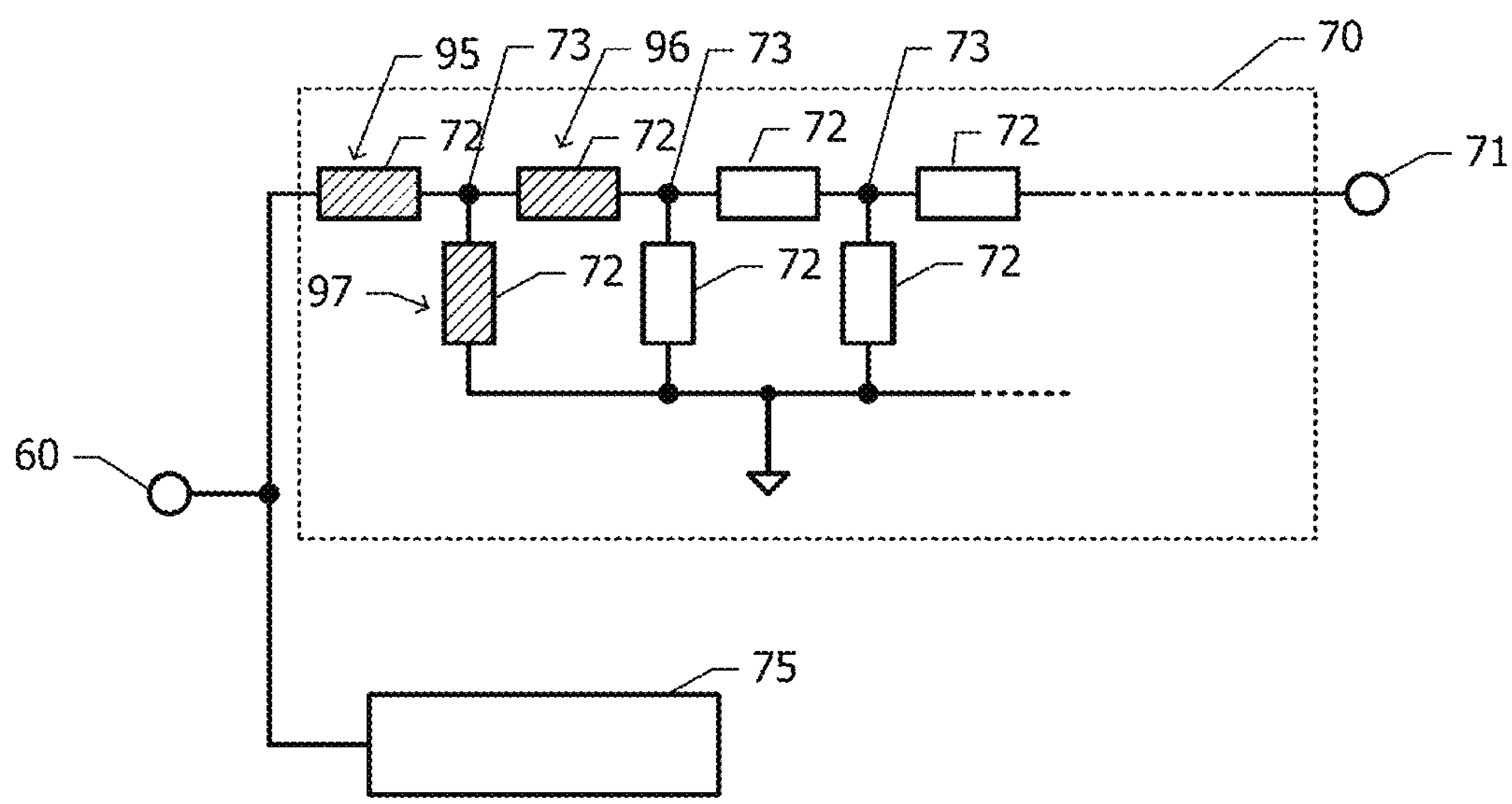
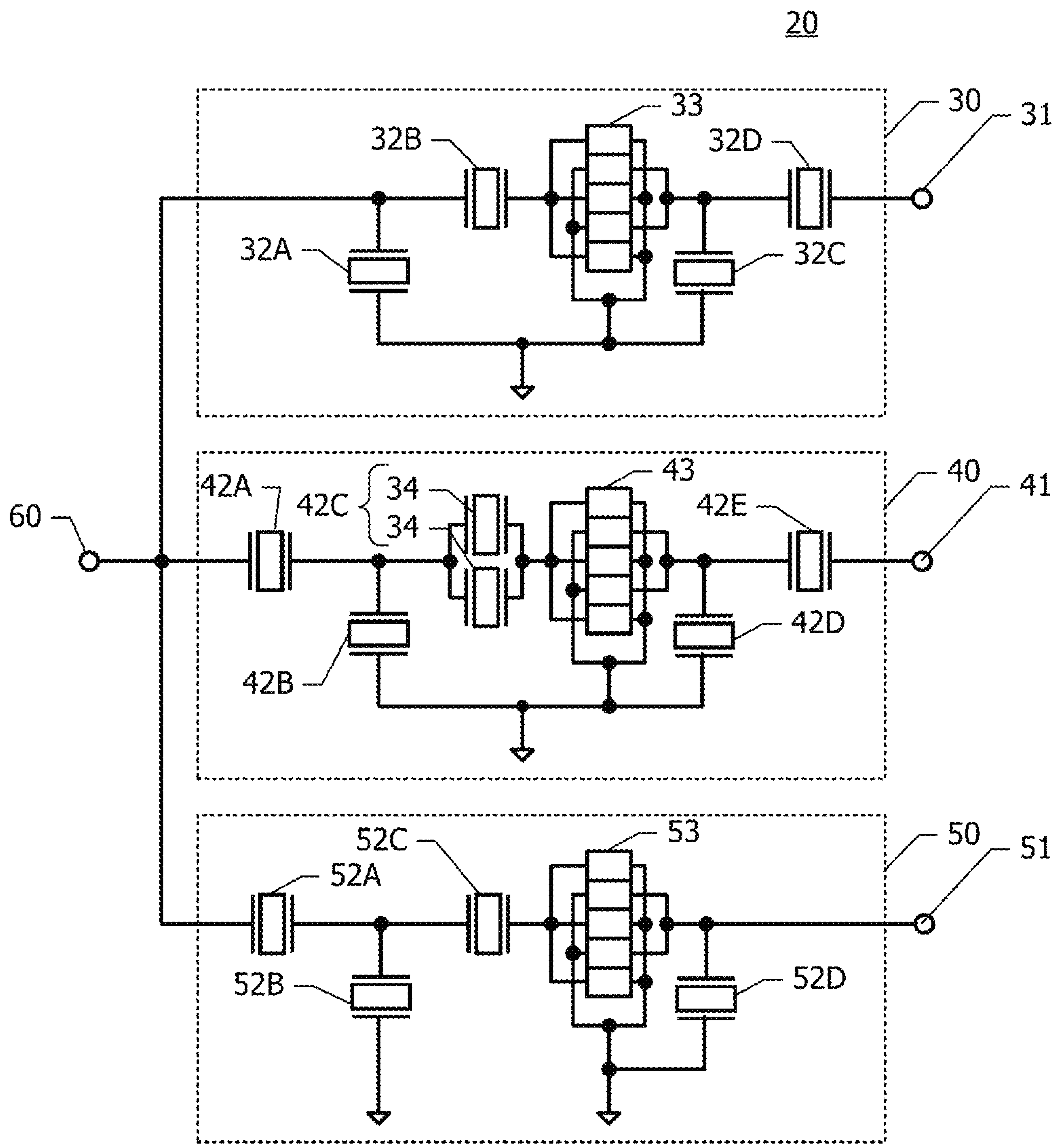


FIG. 14


20
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32D
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42A
42B
42C
34
34
42D
42E
43
50
51
52A
52B
52C
52D
53
60

Fig.15A
(THIRD EMBODIMENT IN FIG.14)

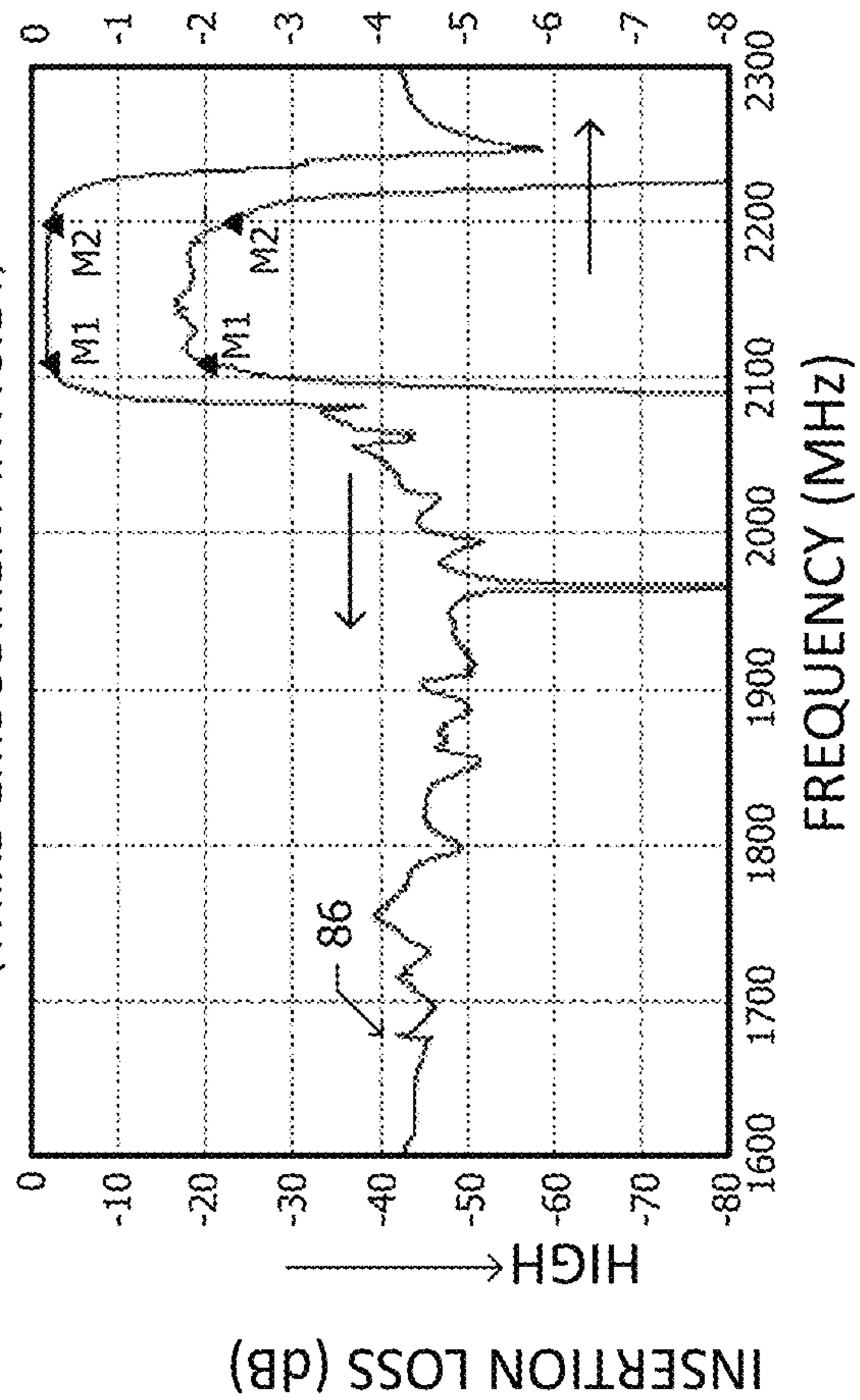


Fig.15B
(THIRD EMBODIMENT IN FIG.14)

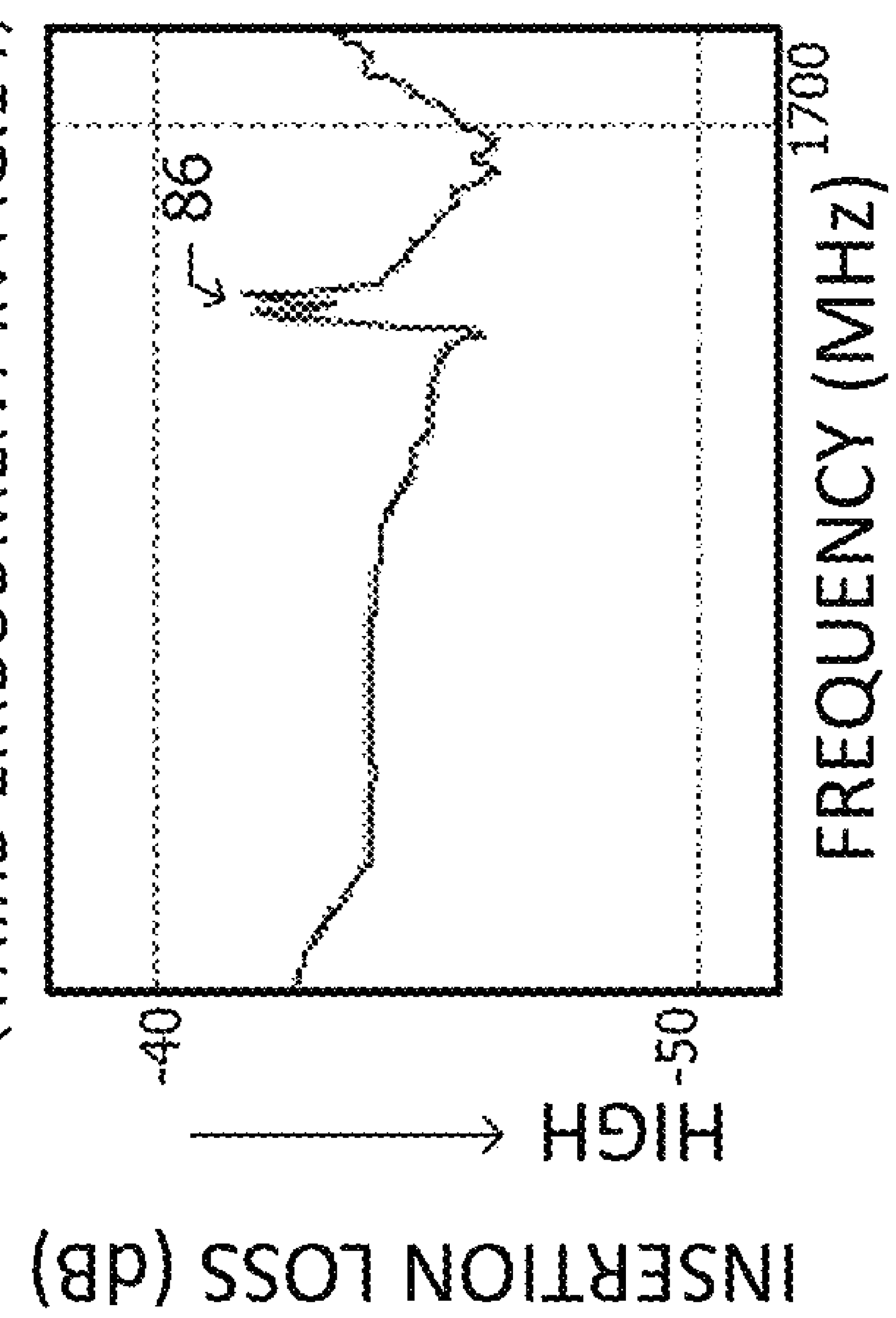


Fig.15C
(COMPARATIVE EXAMPLE IN FIG.7)

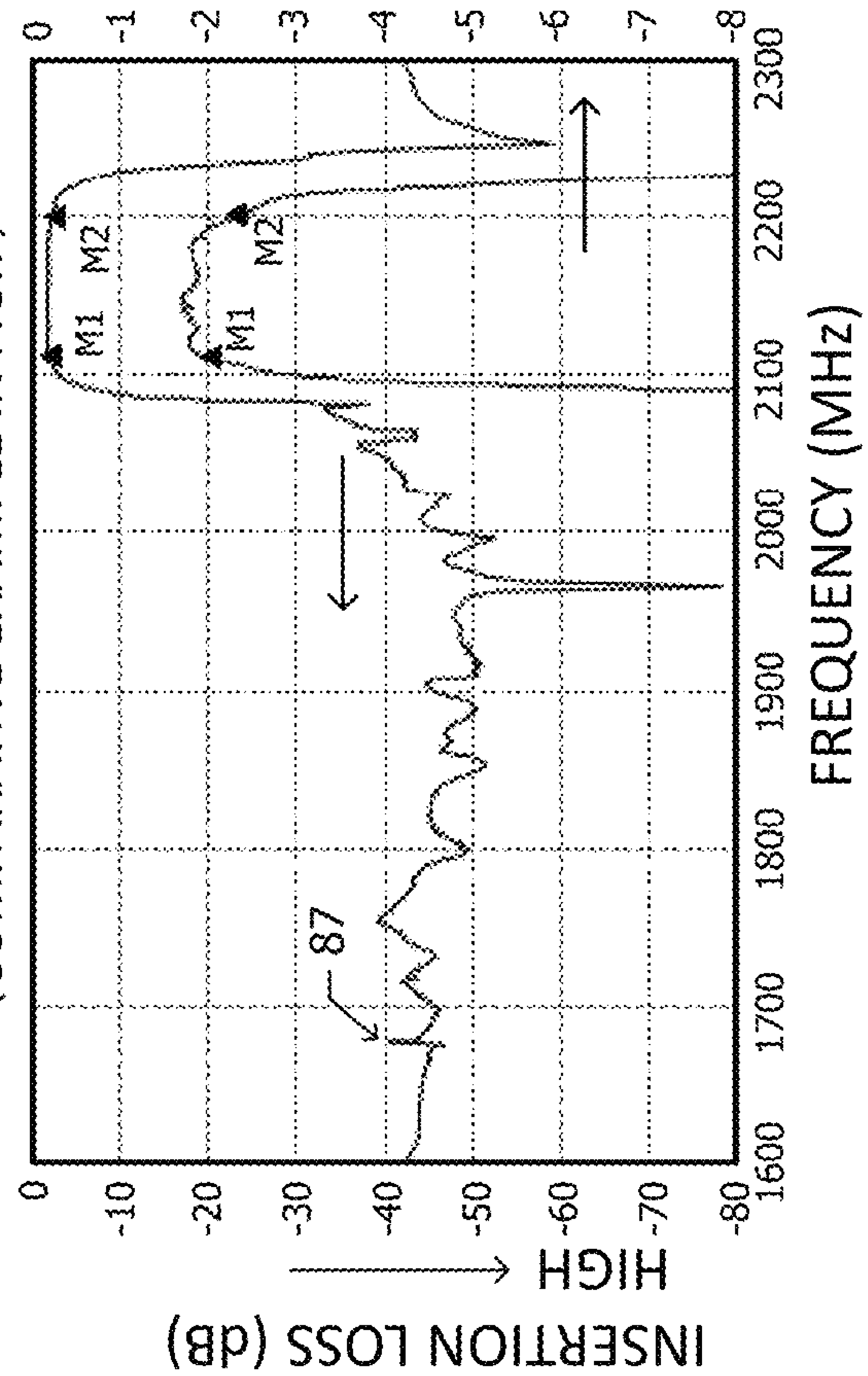


Fig.15D
(COMPARATIVE EXAMPLE IN FIG.7)

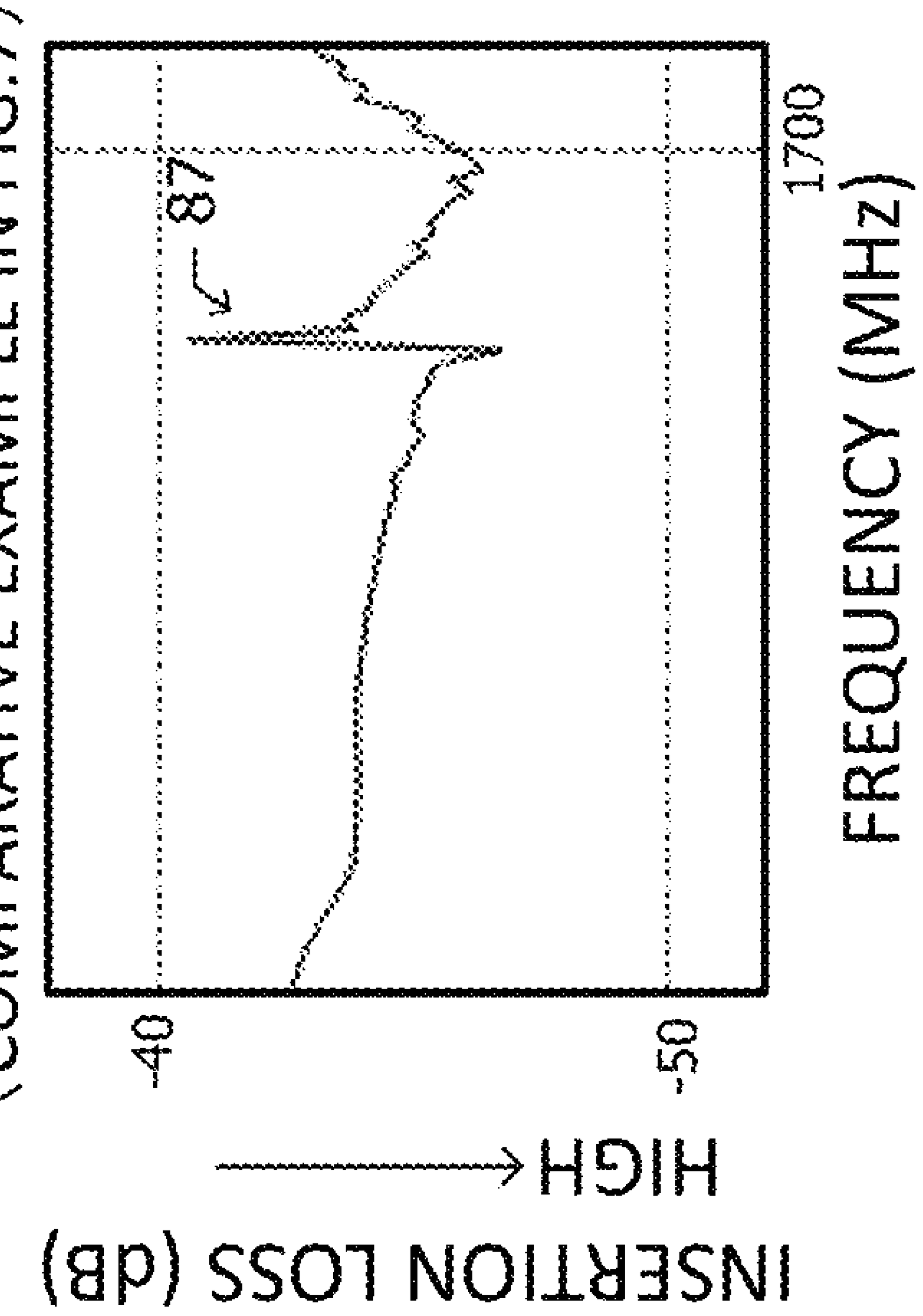


FIG. 16

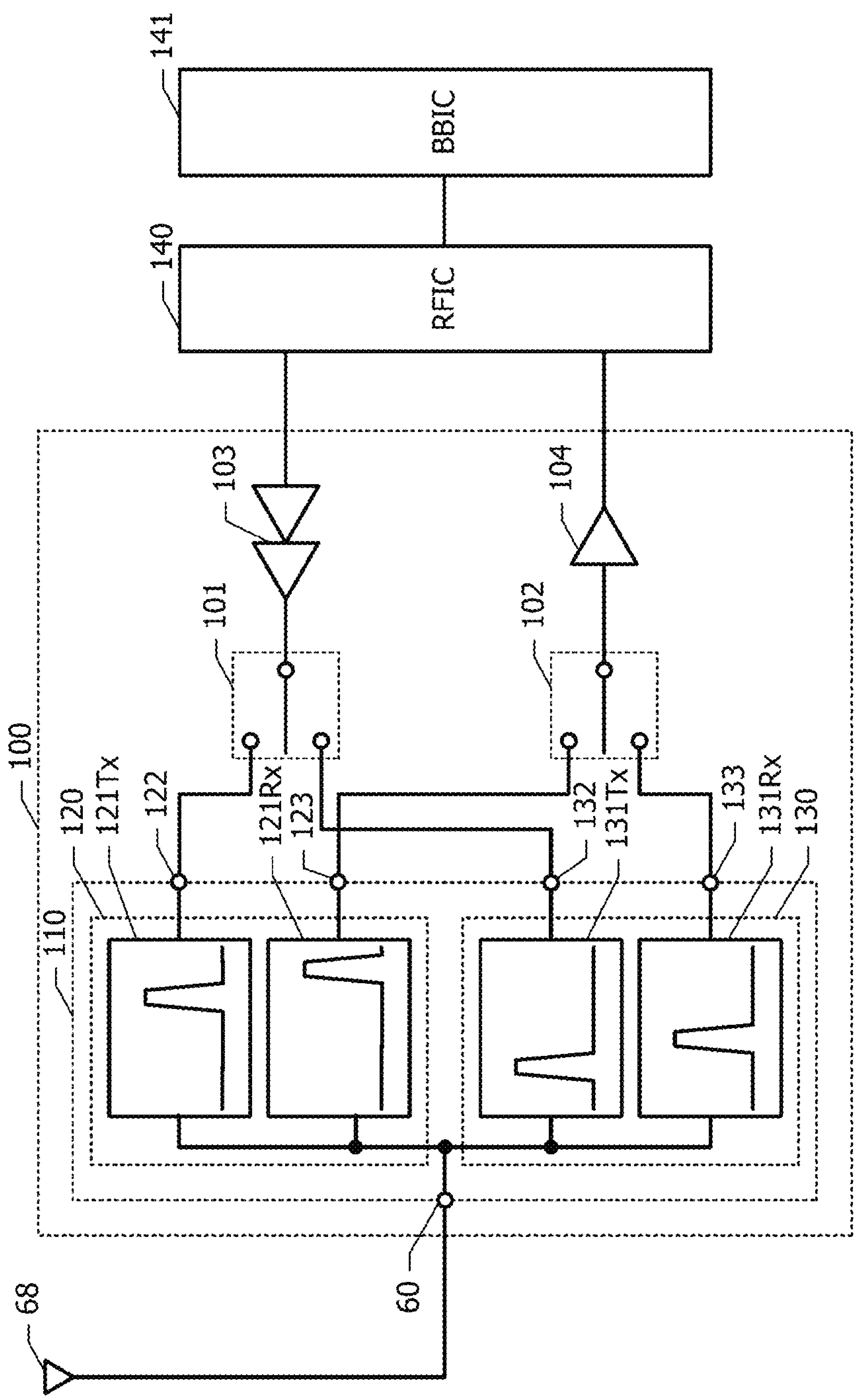

141
BBIC
140
RFIC
103
104
101
102
100
120
121Tx
122
121Rx
123
132
131Tx
133
131Rx
130
110
60
68

FIG. 17A

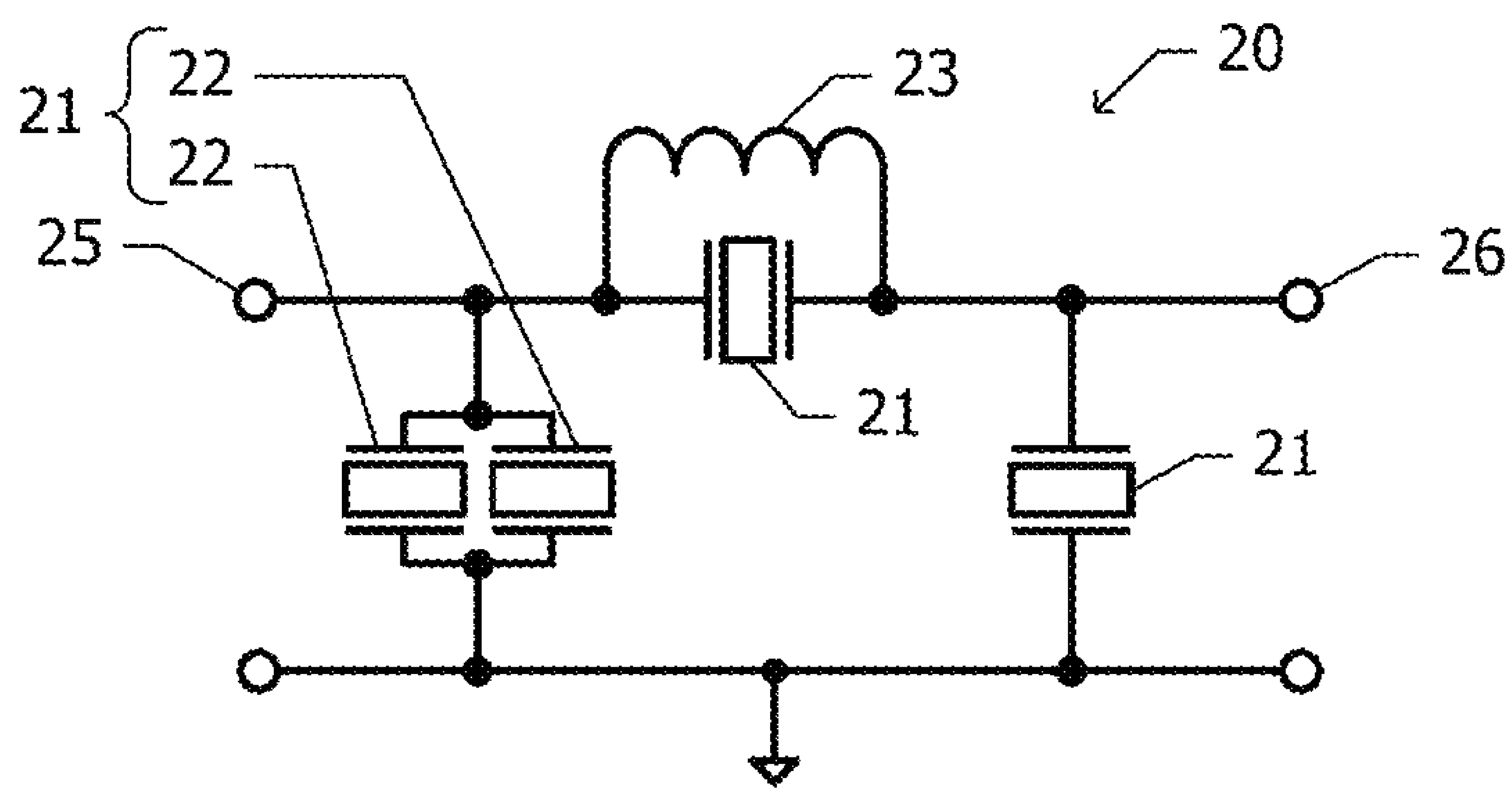
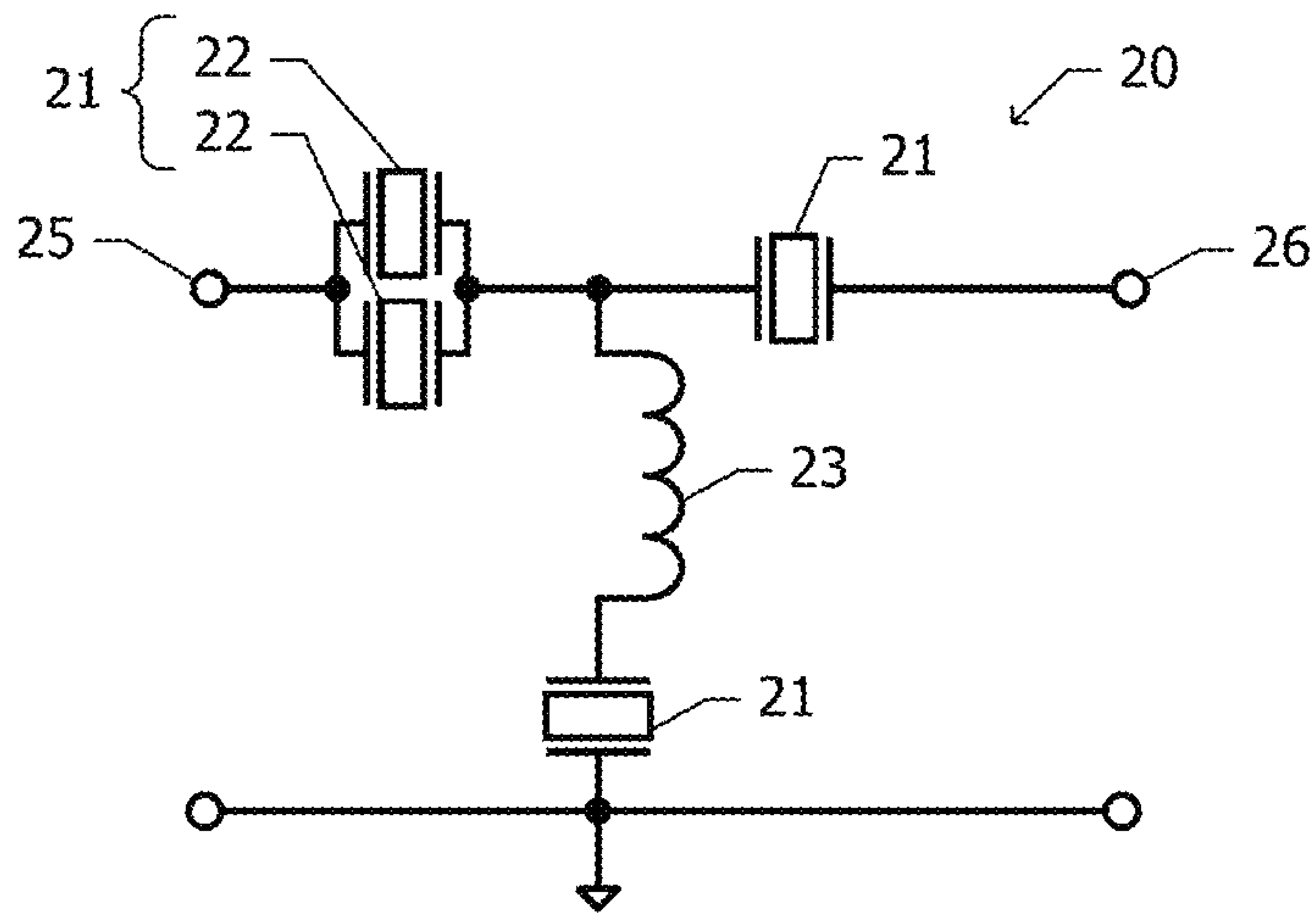


FIG. 17B



FILTER DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority to Japanese Patent Application No. 2020-110656 filed on Jun. 26, 2020 and Japanese Patent Application No. 2019-223404 filed on Dec. 11, 2019. The entire contents of these applications are hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a filter device.

2. Description of the Related Art

As a bandpass filter used in a communication apparatus, such as in a mobile information terminal, a filter using surface acoustic wave (SAW) elements is utilized. To support multiple frequency bands with one antenna, a multiplexer including multiple duplexers is used. A multiplexer includes a plurality of bandpass filters, for example. An example of such a multiplexer is disclosed in International Publication No. 2018/003297.

To achieve a desired pass band, a bandpass filter using SAW elements includes multiple SAW resonators connected with each other. In a SAW resonator utilizing leaky waves or shear horizontal (SH) waves as the main waves, resonance may be produced due to unwanted waves, such as Rayleigh waves, at a frequency lower than the fundamental resonant frequency of the main waves. This may cause a ripple in the bandpass characteristics in the stopband of the bandpass filter, which may adversely influence the attenuation characteristics in the stopband of the bandpass filter.

Additionally, when a plurality of bandpass filters having different pass bands are connected to a single common terminal, a ripple due to unwanted waves produced in one bandpass filter may adversely influence the bandpass characteristics in the pass band of a different bandpass filter if the frequency of the ripple is included in the pass band of this different bandpass filter.

SUMMARY OF THE INVENTION

Preferred embodiments of the present invention provide filter devices that are each able to reduce ripples caused by unwanted waves.

According to a preferred embodiment of the present invention, a filter device includes a common terminal, first and second individual terminals, and first and second filters. The first filter is connected between the common terminal and the first individual terminal. The second filter is connected between the common terminal and the second individual terminal. The pass band of the second filter is in a frequency range lower than the pass band of the first filter. The first filter includes a plurality of surface acoustic wave (SAW) resonators. At least one of the plurality of SAW resonators is includes a plurality of divided resonators connected in parallel with each other. Each of the plurality of divided resonators includes an interdigital transducer (IDT). The plurality of divided resonators include at least two divided resonators. Among the at least two divided resonators, the pitch of the IDT of a divided resonator is different from that of another divided resonator.

According to a preferred embodiment of the present invention, a filter device includes a SAW filter including plurality of SAW resonators. At least one of the plurality of SAW resonators includes a plurality of divided resonators connected in parallel with each other. Each of the plurality of divided resonators includes an IDT. Among the plurality of divided resonators, the pitch of the IDT of a divided resonator is different from that of another divided resonator. (Pmax−Pmin)/Pa is about 0.7% or smaller, where Pa is the average of the pitches of the IDTs of the plurality of divided resonators, and Pmax and Pmin are the maximum value and the minimum value, respectively, of the pitches of the IDTs of the plurality of divided resonators.

According to a preferred embodiment of the present invention, a filter device includes a substrate and a plurality of SAW resonators. The substrate is made of a piezoelectric material. The plurality of SAW resonators are disposed on the substrate and are connected with each other. At least one of the plurality of SAW resonators includes a plurality of divided resonators connected in parallel with each other. Each of the plurality of divided resonators includes an IDT. Among the plurality of divided resonators, the pitch of the IDT of a divided resonator is different from that of another divided resonator. Among the plurality of divided resonators, the arrangement direction of electrode fingers of the IDT of a divided resonator is parallel or substantially parallel with that of another divided resonator. The IDTs of the plurality of divided resonators are displaced from each other in a direction perpendicular or substantially perpendicular to the arrangement direction of the electrode fingers.

With the use of SAW resonators including a plurality of parallel-connected divided resonators, ripples caused by unwanted waves produced in each of the SAW resonators are able to be reduced.

The above and other elements, features, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an equivalent circuit diagram of a filter device according to a first preferred embodiment of the present invention.

FIG. **2** is an equivalent circuit diagram of a filter device according to a comparative example.

FIG. **3**A is a graph schematically illustrating the bandpass characteristics of the filter device of the first preferred embodiment of the present invention shown in FIG. **1**.

FIG. **3**B is a graph schematically illustrating the bandpass characteristics of the filter device of the comparative example shown in FIG. **2**.

FIGS. **4**A and **4**B are schematic plan views illustrating examples of the arrangement of interdigital transducers (IDTs) of two parallel-connected divided resonators of the filter device shown in FIG. **1**.

FIG. **5** is an equivalent circuit diagram of a filter device according to a second preferred embodiment of the present invention.

FIG. **6** illustrates the arrangement of SAW resonators, longitudinally coupled SAW filters, wires, terminals, and other components included in the filter device of the second preferred embodiment of the present invention as viewed from above.

FIG. **7** is an equivalent circuit diagram of a filter device according to a comparative example.

FIGS. **8**A and **8**B are graphs illustrating the measurement results of the bandpass characteristics in the path from a common terminal to a second individual terminal in the filter device of the second preferred embodiment of the present invention shown in FIG. **5**.

FIGS. **8**C and **8**D are graphs illustrating the measurement results of the bandpass characteristics in the path from a common terminal to a second individual terminal in the filter device of the comparative example shown in FIG. **7**.

FIG. **9** is a graph illustrating the measurement results of the bandpass characteristics in the path from the common terminal to a first individual terminal in the filter device of the second preferred embodiment of the present invention shown in FIG. **5** and those of the filter device of the comparative example shown in FIG. **7**.

FIG. **10**A is an enlarged graph showing a specific frequency range in the graph of FIG. **9**.

FIG. **10**B is an enlarged graph showing a specific frequency range in the graph of FIG. **10**A.

FIG. **11** is a graph illustrating the simulation results of the bandpass characteristics obtained while the IDT pitch of one divided resonator of the filter device of the second preferred embodiment of the present invention is fixed and the IDT pitch of the other divided resonator is varied.

FIG. **12** is a graph illustrating the relationship between the pass band of a first bandpass filter and that of a second bandpass filter in the filter device of the second preferred embodiment of the present invention on the frequency axis.

FIG. **13**A is a circuit diagram of a ladder bandpass filter configured similarly to the first bandpass filter of the filter device of the second preferred embodiment of the present invention.

FIG. **13**B is a circuit diagram of a ladder bandpass filter configured differently from that in FIG. **13**A.

FIG. **14** is an equivalent circuit diagram of a filter device according to a third preferred embodiment of the present invention.

FIGS. **15**A and **15**B are graphs illustrating the measurement results of the bandpass characteristics in the path from a common terminal to a second individual terminal in the filter device of the third preferred embodiment of the present invention shown in FIG. **14**.

FIGS. **15**C and **15**D are graphs illustrating the measurement results of the bandpass characteristics in the path from the common terminal to the second individual terminal in the filter device of the comparative example shown in FIG. **7**.

FIG. **16** is a block diagram of a communication apparatus according to a fourth preferred embodiment of the present invention.

FIG. **17**A is an equivalent circuit diagram of a filter device according to a fifth preferred embodiment of the present invention.

FIG. **17**B is an equivalent circuit diagram of a filter device according to a modified example of the fifth preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described in detail below with reference to the drawings.

First Preferred Embodiment

A filter device according to a first preferred embodiment will be described below with reference to FIGS. **1** through **4**B.

FIG. **1** is an equivalent circuit diagram of a filter device **20** according to the first preferred embodiment. The filter device **20** is a ladder filter device including a plurality of surface acoustic wave (SAW) resonators **21**. Parallel arms branch off from branch nodes **27** of a series arm connecting a first terminal **25** and a second terminal **26**. Each of the parallel arms is grounded on the other side opposite the corresponding branch node of the series arm. A ladder filter device refers to a filter device using series elements and parallel elements of a ladder circuit as resonators. A ladder circuit includes one input terminal, one output terminal, and a ground terminal to which an input/output ground potential is supplied. The series elements are elements connected between the input terminal and the output terminal of the ladder circuit. The parallel elements are elements connected between the corresponding series elements and the ground potential.

At least one SAW resonator **21** is interposed between two adjacent branch nodes **27** of the series arm and also on each of multiple parallel arms. The SAW resonators **21** disposed on the series arm may also be called series arm resonators, while the SAW resonators **21** disposed on the parallel arms may also be called parallel arm resonators. The SAW resonator **21**, which is the series arm resonator disposed between the first and second branch nodes as seen from the first terminal **25**, includes two divided resonators **22** connected in parallel with each other. Each of the divided resonators **22** includes an interdigital transducer (IDT) including a pair of interlocking comb-shaped electrodes. The pitch of multiple electrode fingers of the IDT (hereinafter simply called the IDT pitch) of one divided resonator **22** is different from that of the other divided resonator **22**. The SAW resonators **21** are designed to utilize, for example, leaky waves or shear horizontal (SH) waves as the main waves.

In a broad sense, each of the divided resonators **22** can be regarded as one SAW resonator. In this specification, however, a SAW resonator including a plurality of parallel-connected divided resonators is distinguished from a SAW resonator which is a resonator divided from this SAW resonator. Due to the manufacturing variations, the IDT pitch may be varied within an allowance. In this case, the IDT pitch P is defined as $P=L/(N-1)$ where L is the center-to-center distance between the electrode fingers of an IDT positioned at both ends and N is the number of electrode fingers.

Advantages of the first preferred embodiment will be explained below in comparison with a comparative example.

FIG. **2** is an equivalent circuit diagram of a filter device **20** according to a comparative example. The circuit configuration of the filter device **20** according to the comparative example is the same or substantially the same as that of the first preferred embodiment shown in FIG. **1**, except for the following point. As opposed to the SAW resonator **21** including the two divided resonators **22** in the first preferred embodiment, the corresponding SAW resonator **21** in the comparative example is not divided into multiple resonators, but includes the single SAW resonator. The other SAW resonators **21** in the comparative example have the same or substantially the same characteristics as those of the first preferred embodiment.

FIG. **3**A is a graph schematically illustrating the bandpass characteristics of the filter device **20** according to the first preferred embodiment (FIG. **1**). FIG. **3**B is a graph schematically illustrating the bandpass characteristics of the filter device **20** according to the comparative example (FIG. **2**). In FIGS. **3**A and **3**B, only distinctive portions are shown in detail, while the other portions are shown in a simplified manner. In the graphs, the horizontal axis indicates the frequency, while the vertical axis indicates the insertion loss. The insertion loss increases downward on the vertical axis.

Both of the filter device **20** of the first preferred embodiment and that of the comparative example are bandpass filters having a lower cutoff frequency at fL and a higher cutoff frequency at fH. In the filter device **20** of the first preferred embodiment (FIG. **1**), two ripples **80** occur in the frequency range lower than the pass band. The pass band of a bandpass filter is the frequency band between the lower cutoff frequency and the higher cutoff frequency. As the lower cutoff frequency and the higher cutoff frequency, the frequencies at which the highest level of power in the pass band drops by about 3 dB, in other words, the frequencies at which the smallest insertion loss increases by about 3 dB, are used. The ripples **80** occur due to unwanted waves produced in the respective two divided resonators **22**, and more specifically, due to Rayleigh waves. Ripples caused by Rayleigh waves may also be called a Rayleigh response. Since the IDT pitch of one divided resonator **22** is different from that of the other divided resonator **22**, the resonant frequencies of the two divided resonators **22** corresponding to the unwanted waves slightly differ from each other. This is why the two ripples **80** occur in response to the two divided resonators **22**.

In contrast, in the filter device **20** of the comparative example (FIG. **2**), the SAW resonator **21** corresponding to the SAW resonator **21** including the two divided resonators **22** in the first preferred embodiment includes only a single SAW resonator. As a ripple caused by unwanted waves produced in this SAW resonator **21**, only one ripple **81** is observed, as shown in FIG. **3**B. The insertion loss at the frequency at which the ripple **81** is observed is smaller than that in the other portions of the stopband, thus failing to obtain desired filter characteristics. It is thus preferable to regulate a drop in the insertion loss caused by the ripple **81** so that the insertion loss at the frequency of the ripple **81** becomes as large as that in the other portions of the stopband.

In the first preferred embodiment, the two ripples **80** occur in response to the unwanted waves. Accordingly, a drop in the insertion loss caused by each of the two ripples **80** becomes smaller than that by the single ripple **81** in the comparative example. In the first preferred embodiment, therefore, the attenuation characteristics in the frequency bands other than the pass band are not decreased as much as those of the comparative example.

The difference in the IDT pitch between the two divided resonators **22** is small, and the total capacitance of the two divided resonators **22** is equal or substantially equal to the capacitance of the corresponding single SAW resonator **21** of the filter device **20** of the comparative example. Thus, even if the single SAW resonator **21** is replaced by the two divided resonators **22** after a filter is designed with the circuit configuration of the comparative example (FIG. **2**), the filter characteristics of the pass band and its adjacent bands remain almost unchanged. It is thus not necessary to design a new filter in the configuration in which the single SAW resonator **21** is replaced by the two divided resonators **22**. Accordingly, it does not become more difficult to design the filter device **20** of the first preferred embodiment than to design the comparative example.

If the difference in the IDT pitch between the two divided resonators **22** is too small, the two ripples **80** occurring in response to unwanted waves do not sufficiently separate from each other. This fails to fully achieve the advantageous effect of regulating a drop in the insertion loss caused by the ripples **80**. If the difference in the IDT pitch between the two divided resonators **22** is too large, the filter characteristics of the pass band and its adjacent bands significantly vary. It is thus preferable to set the difference in the IDT pitch between the two divided resonators **22** so that the ripples **80** can be clearly separated from each other and the filter characteristics of the pass band and its adjacent bands are not significantly influenced. As an example, Pd/Pa is preferably set to be about 0.02% to about 0.7%, where Pd is the difference in the IDT pitch between the two divided resonators **22** and Pa is the average of the IDT pitches of the two divided resonators **22**. The basis for the upper limit and the lower limit in this preferable range of the difference in the IDT pitch will be discussed later with reference to FIG. **11**.

The arrangement of the IDTs of the two divided resonators **22** (FIG. **1**) will be discussed below with reference to FIGS. **4**A and **4**B.

FIG. **4**A is a schematic plan view illustrating an example of the arrangement of the IDTs of the two divided resonators **22** (FIG. **1**). Electrode fingers of the IDTs shown in FIG. **4**A are fewer than those of the actual IDTs. A pair of interlocking comb-shaped electrodes **221** define an IDT **222**. The pitch of the IDT **222** of one divided resonator **22** is indicated by P**1**, while that of the other divided resonator **22** is indicated by P**2**. The multiple electrode fingers of the IDTs **222** of the two divided resonators **22** are aligned. Reflectors **223** are disposed at both sides of each of the two IDTs **222**. The reflectors **223** reflect SAWs having the resonance wavelength of the corresponding IDT **222**.

FIG. **4**B is a schematic plan view illustrating another example of the arrangement of the IDTs of the two divided resonators **22** (FIG. **1**). In the example in FIG. **4**B, the arrangement direction of the plurality of electrode fingers of the IDT **222** of one divided resonator **22** is parallel or substantially parallel with that of the other divided resonator **22**. The two IDTs **222** are displaced from each other in the direction perpendicular or substantially perpendicular to the arrangement direction of the electrode fingers. The reflector **223** disposed at one side of one IDT **222** partially overlaps the other IDT **222** or the reflector **223** disposed at one side of the other IDT **222** in the arrangement direction of the electrode fingers.

It is possible to make the total dimensions of the two divided resonators **22** shown in FIG. **4**A smaller than those in FIG. **4**B in the direction perpendicular or substantially perpendicular to the arrangement direction of the electrode fingers. It is possible to make the total dimensions of the two divided resonators **22** shown in FIG. **4**B smaller than those in FIG. **4**A in the direction parallel or substantially parallel with the arrangement direction of the electrode fingers. A preferable one of the two arrangements shown in FIGS. **4**A and **4**B may be selected in terms of the relationship with the other SAW resonators **21** (FIG. **1**).

Various modified examples of the first preferred embodiment will be described below.

In the first preferred embodiment (FIG. **1**), the SAW resonator **21** interposed between the first and second branch nodes **27** of the series arm as seen from the first terminal **25** includes two divided resonators **22**. Another SAW resonator **21** may include two divided resonators **22**. For example, the SAW resonator **21** disposed between branch nodes **27** of the series arm positioned closer to the second terminal **26** with respect to the second branch node **27** seen from the first terminal **25** may include two divided resonators **22**. A SAW resonator **21** disposed on a parallel arm may include two divided resonators **22**.

In the first preferred embodiment (FIG. **1**), one SAW resonator **21** includes two divided resonators **22**, for example. Alternatively, each of multiple SAW resonators **21** may include two parallel-connected divided resonators **22**. Additionally, one or multiple SAW resonators **21** may each include three or more parallel-connected divided resonators **22**, for example. In this case, it is preferable that (Pmax−Pmin)/Pa is about 0.02% to about 0.7%, where Pmax and Pmin are the maximum value and the minimum value, respectively, of the IDT pitches of the multiple divided resonators **22**, and Pa is the average of the IDT pitches of the multiple divided resonators **22**.

In the first preferred embodiment (FIG. **1**), both of the series arm resonator and the parallel arm resonator are connected to the first terminal **25**, while only the series arm resonator is connected to the second terminal **26**. Alternatively, both of the series arm resonator and the parallel arm resonator may be connected to each of the first and second terminals **25** and **26**. Conversely, parallel arm resonators may be connected to neither of the first terminal **25** nor the second terminal **26**.

In the first preferred embodiment (FIG. **1**), the ladder filter includes a plurality of series arm resonators and a plurality of parallel arm resonators, for example. However, the ladder filter may include one series arm resonator and a plurality of parallel arm resonators, or a plurality of series arm resonators and one parallel arm resonator, or one series arm resonator and one parallel arm resonator. In such a ladder filter, at least one SAW resonator may include multiple parallel-connected divided resonators. For example, a T-type filter, a π-type filter, and an L-type filter are examples of such a ladder filter. A filter device including a plurality of SAW resonators provided in a circuit configuration other than that of the ladder filter of the first preferred embodiment (FIG. **1**), may be used. In such a filter device, one of the SAW resonators may include multiple parallel-connected divided resonators.

In the first preferred embodiment (FIG. **1**), leaky waves or SH waves, for example, are preferably utilized as the main waves. Although the ripples **80** occur due to Rayleigh waves, which are unwanted waves, in a stopband of the bandpass characteristics, a drop in the insertion loss caused by the ripples **80** can be regulated. Alternatively, another type of acoustic waves may be utilized as the main waves. In this case, although ripples **80** occur due to unwanted waves in the frequency range lower than the resonant frequency of the main waves, a drop in the insertion loss caused by the ripples **80** can be regulated by the application of the configuration of the first preferred embodiment.

In the first preferred embodiment, the IDT pitch of the same divided resonator **22** is preferably constant or substantially constant. However, the IDT pitch may be changed, for example, progressively or in a stepwise manner in the same divided resonator **22**. The IDT pitch of a SAW resonator **21** other than the SAW resonator **21** including the divided resonators **22** may also be changed. Changing the IDT pitch in the same SAW resonator **21** can reduce ripples in the pass band.

If the IDT pitch is varied in each of the two divided resonators **22**, the average of the IDT pitches of one divided resonator **22** is set to be different from that of the other divided resonator **22**. As an example, when the average IDT pitch of one divided resonator **22** is Pa**1** and that of the other divided resonator **22** is Pa**2**, the difference between the average IDT pitches Pa**1** and Pa**2** is used as the difference Pd in the IDT pitch between the two divided resonators **22**, and the average of the average pitches Pa**1** and Pa**2** is used as the average Pa of the IDT pitches of the two divided resonators **22**. As in the first preferred embodiment, Pd/Pa is preferably set to be about 0.02% to about 0.7%, for example.

Second Preferred Embodiment

A filter device according to a second preferred embodiment of the present invention will be described below with reference to FIGS. **5** through **13**B. An explanation of the elements configured similarly to those of the filter device **20** of the first preferred embodiment (FIG. **1**) will be omitted.

FIG. **5** is an equivalent circuit diagram of a filter device **20** according to the second preferred embodiment. The filter device **20** of the second preferred embodiment includes a first bandpass filter **30**, a second bandpass filter **40**, a third bandpass filter **50**, a common terminal **60**, a first individual terminal **31**, a second individual terminal **41**, and a third individual terminal **51**. The first bandpass filter **30** is connected between the common terminal **60** and the first individual terminal **31**. The second bandpass filter **40** is connected between the common terminal **60** and the second individual terminal **41**. The third bandpass filter **50** is connected between the common terminal **60** and the third individual terminal **51**.

The common terminal **60** is connected to an antenna **68**. An impedance matching inductor **61** is connected between the common terminal **60** and a ground. The first, second, and third individual terminals **31**, **41**, and **51** are connected to a low-noise amplifier **63** via a switch **62**. Impedance matching inductors **65**, **66**, and **67** are respectively connected between the first, second, and third individual terminals **31**, **41**, and **51** and a ground.

The filter device **20** of the second preferred embodiment is a receiver triplexer that separates radio-frequency (RF) signals received by the antenna **68** into RF signals in three frequency bands. For example, the pass bands of the first, second, and third bandpass filters **30**, **40**, and **50** preferably correspond to those standardized by the third generation partnership project (3GPP). More specifically, for example, the pass band of the first bandpass filter **30** is equal or substantially equal to Band **41** downlink frequency band (about 2496 MHz to about 2690 MHz), the pass band of the second bandpass filter **40** is equal or substantially equal to Band **66** downlink frequency band (about 2110 MHz to about 2200 MHz), and the pass band of the third bandpass filter **50** is equal or substantially equal to Band **3** downlink frequency band (about 1805 MHz to about 1880 MHz). That is, the pass band of the second bandpass filter **40** is lower than that of the first bandpass filter **30**, and the pass band of the third bandpass filter **50** is lower than that of the second bandpass filter **40**.

Each of the first, second, and third bandpass filters **30**, **40**, and **50** is preferably a ladder SAW filter, for example.

The first bandpass filter **30** includes SAW resonators **32**A, **32**B, **32**C, and **32**D and one longitudinally coupled SAW filter **33**. The SAW resonator **32**B is disposed between the first and second branch nodes of the series arm as seen from the common terminal **60**. As in the SAW resonator **21** disposed between the first and second branch nodes **27** of the series arm as seen from the first terminal **25** in the filter device **20** of the first preferred embodiment (FIG. **1**), the SAW resonator **32**B includes two parallel-connected divided resonators **34**. The longitudinally coupled SAW filter **33** is inserted between the SAW resonator **32**B and the second branch node.

No SAW resonator is interposed between the common terminal **60** and the first branch node as seen from the common terminal **60**. The SAW resonator **32**D is connected between the second branch node and the first individual terminal **31**. As seen from the common terminal **60**, the SAW resonator **32**A is disposed on the parallel arm which branches off from the first branch node of the series arm, while the SAW resonator **32**C is disposed on the parallel arm which branches off from the second branch node of the series arm. Each of the SAW resonators **32**A, **32**C, and **32**D may include a plurality of divided resonators connected in series with each other.

The second bandpass filter **40** includes five SAW resonators **42**A, **42**B, **42**C, **42**D, and **42**E and one longitudinally coupled SAW filter **43**. The SAW resonator **42**A is connected between the common terminal **60** and the first branch node as seen from the common terminal **60**. The SAW resonator **42**C and the longitudinally coupled SAW filter **43** are connected in series with each other between the first and second branch nodes. The SAW resonator **42**E is connected between the second branch node and the second individual terminal **41**. The SAW resonator **42**B is disposed on the parallel arm which branches off from the first branch node of the series arm, while the SAW resonator **42**D is disposed on the parallel arm which branches off from the second branch node of the series arm. Each of the SAW resonators **42**A through **42**E may include a plurality of series-connected divided resonators.

The third bandpass filter **50** includes four SAW resonators **52**A, **52**B, **52**C, and **52**D and one longitudinally coupled SAW filter **53**. The SAW resonator **52**A is connected between the common terminal **60** and the first branch node as seen from the common terminal **60**. The SAW resonator **52**C and the longitudinally coupled SAW filter **53** are connected in series with each other between the first and second branch nodes. The SAW resonator **52**B is disposed on the parallel arm which branches off from the first branch node of the series arm, while the SAW resonator **52**D is disposed on the parallel arm which branches off from the second branch node of the series arm. Each of the SAW resonators **52**A through **52**D may include a plurality of series-connected divided resonators.

FIG. **6** illustrates the arrangement of the SAW resonators, the longitudinally coupled SAW filters, wires, terminals, and other components included in the filter device **20** of the second preferred embodiment as viewed from above. On the surface of a substrate **28** made of a piezoelectric material, the common terminal **60**, the first through third individual terminals **31**, **41**, and **51**, multiple ground terminals, multiple SAW resonators, multiple longitudinally coupled SAW filters, wires and other components are disposed. As the substrate **28**, a single crystal substrate made of a piezoelectric material, such as $LiTaO_3$ or $LiNbO_3$, for example, may preferably be used.

In FIG. **6**, ground wires are indicated by the sparse hatched portion, while series arm wires are indicated by the dense hatched portion. An insulating film is disposed where two wires cross each other so as to provide electrical insulation therebetween. The SAW resonators, the longitudinally coupled SAW filters, and terminals are designated by the same reference numerals provided to those in the equivalent circuit diagram shown in FIG. **5**. The IDTs of two divided resonators **34** of the SAW resonator **32**B are arranged in the configuration shown in FIG. **4**B.

The filter device **20** of the second preferred embodiment preferably has a length of about 1.8 mm, a width of about 1.4 mm, and a height of about 0.6 mm, for example. The filter device **20** is mounted on a package substrate with its top side facing downward.

Advantages of the second preferred embodiment will be explained below with reference to FIGS. **8**A through **10**B in comparison with a filter device **20** of a comparative example shown in FIG. **7**.

FIG. **7** is an equivalent circuit diagram of the filter device **20** according to the comparative example. In the comparative example, the SAW resonator **32**B of the filter device **20** of the second preferred embodiment is replaced by a single SAW resonator **32**B. The other elements of the comparative example are the same or substantially the same as those of the second preferred embodiment. The filter device **20** of the second preferred embodiment (FIG. **5**) and the filter device **20** of the comparative example (FIG. **7**) were prepared and the bandpass characteristics of the two filter devices **20** were measured.

The characteristics of the SAW resonators and the longitudinally coupled SAW filters of the filter device **20** of the comparative example were determined so that the pass bands of the first, second, and third bandpass filters **30**, **40**, and **50** of the comparative example would match or substantially match Band **41**, Band **66**, and Band **3** downlink frequency bands, respectively. The IDT pitch of the SAW resonator **32**B (FIG. **7**) of the comparative example was first determined. Then, based on the IDT pitch of the SAW resonator **32**B of the comparative example, the IDT pitches of the two divided resonators **34** of the SAW resonator **32**B (FIG. **5**) of the second preferred embodiment were determined. More specifically, the IDT pitch of one divided resonator **34** was set to be the same or substantially the same as that of the SAW resonator **32**B of the comparative example. The IDT pitch of the other divided resonator **34** was set to be slightly smaller than that in the comparative example. The difference in the IDT pitch between the two divided resonators **34** was set to be about 0.06% of the average of the IDT pitches of the two divided resonators **34**.

FIGS. **8**A and **8**B are graphs illustrating the measurement results of the bandpass characteristics in the path from the common terminal **60** to the second individual terminal **41** in the filter device **20** of the second preferred embodiment (FIG. **5**). FIGS. **8**C and **8**D are graphs illustrating the measurement results of the bandpass characteristics in the path from the common terminal **60** to the second individual terminal **41** in the filter device **20** of the comparative example (FIG. **7**). In the graphs, the horizontal axis indicates the frequency (MHz), while the vertical axis indicates the insertion loss (dB). In FIGS. **8**A and **8**C, the scale factor of the vertical axis on the right side is ten times as large as that on the left side. The insertion loss increases downward on the vertical axis. A network analyzer is usually used for measuring the bandpass characteristics.

FIG. **8**B is an enlarged graph showing a specific frequency range in the graph of FIG. **8**A. FIG. **8**D is an enlarged graph showing a specific frequency range in the graph of FIG. **8**C. Markers M**1** and M**2** in the graphs correspond to the frequencies at about 2110 MHz and about 2200 MHz, respectively. The frequency band between the markers M**1** and M**2** is equal or substantially equal to Band **66** downlink frequency band used for the second bandpass filter **40**.

As shown in FIGS. **8**C and **8**D, in the filter device **20** of the comparative example (FIG. **7**), a single large ripple **83** is observed at the frequency of about 2145 MHz. In contrast, in the filter device **20** of the second preferred embodiment (FIG. **5**), two ripples **82** are observed at the frequencies of about 2145 MHz and about 2146.2 MHz. An increase in the insertion loss of each of the two ripples **82** is smaller than that of the ripple **83** in the bandpass characteristics (FIGS. **8**C and **8**D) of the filter device **20** of the comparative example.

FIGS. **9**, **10**A, and **10**B are graphs illustrating the measurement results of the bandpass characteristics in the path from the common terminal **60** to the first individual terminal **31** in the filter device **20** of the second preferred embodiment (FIG. **5**) and those of the filter device **20** of the comparative example (FIG. **7**). In the graphs, the horizontal axis indicates the frequency (MHz), while the vertical axis indicates the insertion loss (dB). The insertion loss increases downward on the vertical axis. In the graphs, the solid line indicates the bandpass characteristics of the filter device **20** of the second preferred embodiment (FIG. **5**), while the broken line indicates the bandpass characteristics of the filter device **20** of the comparative example (FIG. **7**).

FIG. **10**A is an enlarged graph showing a specific frequency range in the graph of FIG. **9**. In FIG. **10**A, the scale factor of the vertical axis on the right side is ten times as large as that on the left side. FIG. **10**B is an enlarged graph showing a specific frequency range in the graph of FIG. **10**A.

As shown in FIGS. **9** and **10**A, almost no difference is observed between the insertion loss in the pass band of the first bandpass filter **30** of the second preferred embodiment and that of the comparative example. FIG. **10**B shows that, in the second preferred embodiment, two ripples **84** occur at the frequencies of about 2145 MHz and about 2146.2 MHz, while, in the comparative example, a single large ripple **85** occurs at the frequency of about 2145 MHz. The two ripples **84** in the second preferred embodiment are due to the unwanted waves produced in the two divided resonators **34** (FIG. **5**). The large ripple **85** in the comparative example is due to the unwanted waves produced in the SAW resonator **32**B (FIG. **7**).

The ripples **82** (FIGS. **8**A and **8**B) observed in the pass band of the second bandpass filter **40** of the second preferred embodiment are caused by the ripples **84** (FIGS. **10**A and **10**B) outside the pass band of the first bandpass filter **30**. The ripple **83** (FIGS. **8**C and **8**D) observed in the pass band of the second bandpass filter **40** of the comparative example is caused by the ripple **85** (FIGS. **10**A and **10**B) outside the pass band of the first bandpass filter **30**. Focusing only on the first bandpass filter **30**, the ripple **85** outside the pass band of the first bandpass filter **30** of the comparative example does not significantly influence the bandpass characteristics of the first bandpass filter **30**. Nevertheless, if the frequency of the ripple **85** is included in the pass band of the second bandpass filter **40**, the ripple **85** significantly influences the bandpass characteristics of the second bandpass filter **40**, as shown in FIG. **8**D.

In the second preferred embodiment, a drop in the insertion loss caused by the ripples **84** (FIG. **10**B) outside the pass band of the first bandpass filter **30** is small. This contributes to regulating an increase in the insertion loss caused by the ripples **82** (FIG. **8**B) in the pass band of the second bandpass filter **40**. It is thus possible to lessen the influence of the ripples **84** on the bandpass characteristics of the second bandpass filter **40**.

As shown in FIGS. **9** and **10**A, even when the SAW resonator **32**B includes the two divided resonators **34** (FIG. **5**), the resulting bandpass characteristics are the same or almost the same as those obtained when the single SAW resonator **32**B (FIG. **7**) is used as in the comparative example. The result of designing the filter device **20** of the comparative example (FIG. **7**) can thus be utilized to design the filter device **20** of the second preferred embodiment (FIG. **5**).

The preferable range of the difference in the IDT pitch between the two divided resonators **34** (FIG. **5**) used in the filter device **20** of the second preferred embodiment will be discussed below with reference to FIG. **11**. The IDT pitch of one divided resonator **34** was fixed to be the same or substantially the same IDT pitch of the SAW resonator **32**B in the comparative example, while the IDT pitch of the other divided resonator **34** was varied. Then, the bandpass characteristics were determined by simulations.

FIG. **11** is a graph illustrating the simulation results. The value of the fixed IDT pitch of one divided resonator **34** is indicated by Pf, while the value of the varied IDT pitch of the other divided resonator **34** is indicated by Pv. The horizontal axis of FIG. **11** represents the result of $(Pv-Pf)/((Pv+Pf)/2)$ (%). That is, the horizontal axis of FIG. **11** represents the ratio of the deviation of the IDT pitch to the average of the IDT pitch. The deviation of the IDT pitch is assumed to be positive when $Pv>Pf$ and to be negative when $Pv<Pf$. The absolute value of the deviation of the IDT pitch will be called the pitch difference.

The vertical axis on the left side in FIG. **11** represents an increase in the insertion loss (dB) caused by the ripples **82** (may also be called the magnitude of ripples **82**) observed in the pass band of the second bandpass filter **40** (FIG. **8**B). The vertical axis on the right side of FIG. **11** represents the largest value of the insertion loss (dB) in the pass band of the first bandpass filter **30**. The insertion loss increases downward on the vertical axis on the right side. In FIG. **11**, the triangles indicate the magnitude of the ripples **82** in the pass band of the second bandpass filter **40**, while the circles indicate the largest value of the insertion loss in the pass band of the first bandpass filter **30**.

The state of the origin of the horizontal axis in FIG. **11** corresponds to the configuration of the filter device **20** of the comparative example (FIG. **7**). The magnitude of the ripples **82** observed in the bandpass characteristics of the second bandpass filter **40** has the largest value when the ratio of the pitch difference to the average of the IDT pitch is zero. This corresponds to the state in which the single large ripple **83** occurs in the pass band of the second bandpass filter **40** in the comparative example, as shown in FIG. **8**D.

As the ratio of the pitch difference to the average of the IDT pitch becomes greater to the value not more than about 0.02%, the magnitude of the ripples **82** gradually becomes smaller. This corresponds to the state in which the two ripples **82** shown in FIG. **8**B partially overlap each other. When the ratio of the pitch difference to the average of the IDT pitch is about 0.02% or greater, the magnitude of the ripples **82** is constant or substantially constant. This corresponds to the state in which the two ripples **82** shown in FIG. **8**B are clearly separated from each other. It is thus preferable that the ratio of the pitch difference to the average of the IDT pitch is, for example, about 0.02% or greater in order to sufficiently provide the advantageous effect of decreasing the magnitude of the ripples **82** in the pass band of the second bandpass filter **40**.

As the ratio of the pitch difference to the average of the IDT pitch increases from zero, the insertion loss in the pass band of the first bandpass filter **30** becomes greater. Especially when the ratio of the pitch difference to the average of the IDT pitch exceeds about 0.7%, the insertion loss rises sharply. It is thus preferable that the ratio of the pitch difference to the average of the IDT pitch is, for example, about 0.7% or smaller. This can regulate an increase in the insertion loss in the pass band caused by the two divided resonators **34** defining the SAW resonator **32**B (FIG. **5**).

The relationship between the pass band of the first bandpass filter **30** and that of the second bandpass filter **40** will be discussed below with reference to FIG. **12**.

FIG. **12** is a graph illustrating the relationship between the pass band PB**1** of the first bandpass filter **30** and the pass band PB**2** of the second bandpass filter **40** on the frequency axis. The lower cutoff frequency and the higher cutoff frequency of the pass band PB**1** of the first bandpass filter **30** are indicated by fL_1 and fH_1, respectively. The lower cutoff frequency and the higher cutoff frequency of the pass band PB**2** of the second bandpass filter **40** are indicated by fL_2 and fH_2, respectively. The higher cutoff frequency fH_2 of the pass band PB**2** of the second bandpass filter **40** is lower than the lower cutoff frequency fL_1 of the pass band PB**1** of the first bandpass filter **30**.

Typically, a Rayleigh response of a SAW resonator occurs in the frequency range which is about 0.7 to about 0.85 times as high as the resonant frequency of the SAW resonator. That is, if the frequency range which is about 0.7 to about 0.85 times as high as the resonant frequency of a SAW resonator of the first bandpass filter **30** overlaps the pass band PB**2** of the second bandpass filter **40**, a Rayleigh response due to the first bandpass filter **30** is likely to occur in the pass band PB**2** of the second bandpass filter **40**.

In the example in FIG. **12**, the pass band PB**2** of the second bandpass filter **40** is included in the frequency range of about 0.7 fL_1 to about 0.85 fH_1. When the pass band PB**1** of the first bandpass filter **30** and the pass band PB**2** of the second bandpass filter **40** have such a relationship, ripples **82** (FIG. **8**B) are likely to occur in the pass band PB**2** of the second bandpass filter **40**.

In addition to when the pass band PB**2** is included in the frequency range of about 0.7 fL_1 to about 0.85 fH_1, when the frequency range of about 0.7 fL_1 to about 0.85 fH_1 is included in the pass band PB**2** of the second bandpass filter **40** or when a portion of the frequency range of about 0.7 fL_1 to about 0.85 fH_1 overlaps a portion of the pass band PB**2** of the second bandpass filter **40**, ripples **82** (FIG. **8**B) are also likely to occur in the pass band PB**2** of the second bandpass filter **40**.

When the pass band PB**1** of the first bandpass filter **30** and the pass band PB**2** of the second bandpass filter **40** have one of the above-described relationships, it is particularly preferable that a filter device is configured as in the filter device **20** of the second preferred embodiment.

A description will be provided, with reference to FIGS. **13**A and **13**B, in which a SAW resonator of the first bandpass filter **30** includes two divided resonators **34** in order to maximize the above-described advantages.

FIG. **13**A is a circuit diagram of a ladder bandpass filter configured similarly to the first bandpass filter **30**. The bandpass filter **70** and another bandpass filter **75** are connected to a common terminal **60**.

A series arm connects the common terminal **60** and an individual terminal **71** of the bandpass filter **70**. A parallel arm is connected between a ground and each of a plurality of branch nodes **73** of the series arm. No SAW resonator is connected between the common terminal **60** and the first branch node **73** as seen from the common terminal **60**. That is, the SAW resonator **72** on the series arm and the SAW resonator **72** on the parallel arm are both connected directly to the common terminal **60**.

If resonance due to unwanted waves is produced in any one of the SAW resonators **72** of the bandpass filter **70**, it influences the other bandpass filter **75** via the common terminal **60**. In this case, even when resonance due to unwanted waves is produced in a SAW resonator **72** separated farther from the common terminal **60**, many other SAW resonators **72** intervene between this SAW resonator **72** and the bandpass filter **75**, thus weakening the resonance as it is transmitted to the bandpass filter **75** via the common terminal **60**. In contrast, if unwanted resonance is produced in a SAW resonator **72** positioned close to the common terminal **60**, it is more easily transmitted to the bandpass filter **75**. From this point of view, it is appropriate that a SAW resonator **72** positioned close to the common terminal **60** includes two divided resonators, thus maximizing the advantageous effect of reducing ripples caused by unwanted resonance.

As an example, in the direction from the common terminal **60** to the first individual terminal **71**, at least one of the SAW resonator **72** disposed on a series arm portion **90** between the first and second branch nodes **73**, the SAW resonator **72** disposed on a series arm portion **91** between the second and third branch nodes **73**, the SAW resonator **72** disposed on a parallel arm **92** which branches off from the first branch node **73**, and the SAW resonator **72** disposed on a parallel arm **93** which branches off from the second branch node **73** (these SAW resonators **72** are indicated by the hatched portions in FIG. **13**A) includes two parallel-connected divided resonators.

FIG. **13**B is a circuit diagram of a ladder bandpass filter **70** configured differently from that in FIG. **13**A. A SAW resonator **72** is connected between the common terminal **60** and the first branch node **73** as seen from the common terminal **60**. In this configuration, in the direction from the common terminal **60** to the first individual terminal **71**, at least one of the SAW resonator **72** disposed on a series arm portion **95** between the common terminal **60** and the first branch node **73**, the SAW resonator **72** disposed on a series arm portion **96** between the first and second branch nodes **73**, and the SAW resonator **72** disposed on a parallel arm **97** which branches off from the first branch node **73** (these SAW resonators **72** are indicated by the hatched portions in FIG. **13**B) includes two parallel-connected divided resonators.

A modified example of the second preferred embodiment will be described below. Instead of the second bandpass filter **40** (FIG. **5**) of the second preferred embodiment, a low pass filter or a band elimination filter may be used. In this modification, advantages similar to those of the second preferred embodiment can be obtained. That is, although ripples caused by the divided resonators **34** of the first bandpass filter **30** occur in the pass band of the low pass filter or the band elimination filter, an increase in the insertion loss caused by the ripples can be regulated.

Third Preferred Embodiment

A filter device according to a third preferred embodiment of the present invention will be described below with reference to FIGS. **14** through **15**D. An explanation of the elements configured similarly to those of the filter device **20** (FIGS. **5** and **6**) of the second preferred embodiment will be omitted.

FIG. **14** is an equivalent circuit diagram of a filter device **20** according to the third preferred embodiment. In the second preferred embodiment, the SAW resonator **32**B of the first bandpass filter **30** includes two divided resonators **34**. In the third preferred embodiment, a SAW resonator **42**C of the second bandpass filter **40** includes two divided resonators **34**. The SAW resonator **32**B of the first bandpass filter **30** includes the single SAW resonator.

FIGS. **15**A and **15**B are graphs illustrating the measurement results of the bandpass characteristics in the path from the common terminal **60** to the second individual terminal **41** in the filter device **20** of the third preferred embodiment (FIG. **14**). FIGS. **15**C and **15**D are graphs illustrating the measurement results of the bandpass characteristics in the path from the common terminal **60** to the second individual terminal **41** in the filter device **20** of the comparative example (FIG. **7**). The bandpass characteristics of the comparative example shown in FIGS. **15**C and **15**D are the same or substantially the same bandpass characteristics shown in FIGS. **8**C and **8**D. However, the frequency ranges on the horizontal axis of the bandpass characteristics in FIGS. **15**C and **15**D are different from those in FIGS. **8**C and **8**D.

In the graphs in FIGS. **15**A through **15**D, the horizontal axis indicates the frequency (MHz), while the vertical axis indicates the insertion loss (dB). In FIGS. **15**A and **15**C, the scale factor of the vertical axis on the right side is ten times as large as that on the left side. The insertion loss increases downward on the vertical axis. FIG. **15**B is an enlarged graph showing a specific frequency range in the graph of FIG. **15**A. FIG. **15**D is an enlarged graph showing a specific frequency range in the graph of FIG. **15**C. Markers M1 and M2 in the graphs correspond to the frequencies at about 2110 MHz and about 2200 MHz, respectively.

Two ripples **86** (FIGS. **15**A and **15**B) are observed in the bandpass characteristics of the filter device **20** of the third preferred embodiment. In the comparative example, a single ripple **87** (FIGS. **15**C and **15**D) is observed in the bandpass characteristics of the filter device **20**. The ripples **86** and **87**, which are observed at the frequency of about 1677 MHz, are due to unwanted waves produced in the SAW resonator **42**C of the second bandpass filter **40**.

Advantages of the third preferred embodiment will be described below. A drop in the insertion loss caused by a ripple will be measured by the height of the ripple. The heights of the two ripples **86** in the third preferred embodiment are lower than that of the ripple **87** in the comparative example. The reason why the heights of the ripples **86** are lower than that of the ripple **87** is that the SAW resonator **42**C of the second bandpass filter **40** includes two divided resonators **34**. Lower heights of the ripples **86** can lessen the influence of the ripples **86** on the bandpass characteristics in the path from the common terminal **60** to the second individual terminal **41**.

A modified example of the third preferred embodiment will be described below. In the third preferred embodiment, the SAW resonator **42**C of the second bandpass filter **40** includes two divided resonators **34**. Alternatively, another SAW resonator of the second bandpass filter **40** may include two divided resonators. At least one SAW resonator of the third bandpass filter **50** may include two divided resonators.

Fourth Preferred Embodiment

A communication apparatus according to a fourth preferred embodiment of the present invention will be described below with reference to FIG. **16**. The filter device **20** of the second preferred embodiment is used in the communication apparatus of the fourth preferred embodiment. An explanation of the elements configured similarly to those of the filter device **20** of the second preferred embodiment (FIGS. **5** and **6**) will be omitted.

FIG. **16** is a block diagram of the communication apparatus according to the fourth preferred embodiment. The communication apparatus includes a radio-frequency (RF) front-end circuit **100**, a radio-frequency (RF) signal processing circuit (radio-frequency integrated circuit (RFIC)) **140**, a baseband signal processing circuit (baseband integrated circuit (BBIC) **141**, and an antenna **68**. The RF front-end circuit **100** includes a quadplexer **110**, a transmit switch **101**, a receive switch **102**, a power amplifier **103**, and a low-noise amplifier **104**. The quadplexer **110** includes two duplexers **120** and **130**. The duplexer **120** includes a transmit bandpass filter **121**Tx and a receive bandpass filter **121**Rx. The duplexer **130** includes a transmit bandpass filter **131**Tx and a receive bandpass filter **131**Rx.

The duplexer **120** is a Band **41** transmit/receive duplexer, while the duplexer **130** is a Band **66** transmit/receive duplexer, for example. The transmit bandpass filter **121**Tx is disposed between a common terminal **60** and an individual terminal **122**. The receive bandpass filter **121**Rx is disposed between the common terminal **60** and an individual terminal **123**. The transmit bandpass filter **131**Tx is disposed between the common terminal **60** and an individual terminal **132**. The receive bandpass filter **131**Rx is disposed between the common terminal **60** and an individual terminal **133**. As these bandpass filters, SAW filters are used. The antenna **68** is connected to the common terminal **60**.

A transmit RF signal output from the power amplifier **103** is input into one of the individual terminals **122** and **132** via the transmit switch **101**. The transmit RF signal passes through the corresponding one of the transmit bandpass filters **121**Tx and **131**Tx and is sent from the antenna **68**. A received RF signal received by the antenna **68** passes through one of the receive bandpass filters **121**Rx and **131**Rx and is input into the low-noise amplifier **104** via the receive switch **102**.

The RF signal processing circuit **140** converts a received RF signal output from the low-noise amplifier **104** into a lower frequency signal and outputs it to the baseband signal processing circuit **141**. The RF signal processing circuit **140** converts a transmit RF signal input from the baseband signal processing circuit **141** into a higher frequency signal and outputs it to the power amplifier **103**. The baseband signal processing circuit **141** performs various signal processing operations on a baseband signal.

Advantages of the fourth preferred embodiment will be explained below.

The receive bandpass filter **121**Rx corresponds to the first bandpass filter **30** of the filter device **20** of the second preferred embodiment (FIG. **5**), while the receive bandpass filter **131**Rx corresponds to the second bandpass filter **40** of the filter device **20** (FIG. **5**). The receive bandpass filter **121**Rx is configured as in the first bandpass filter **30**. Thus, the bandpass characteristics of the receive bandpass filter **131**Rx are less likely to be influenced by unwanted resonance produced in the receive bandpass filter **121**Rx.

As described above, unwanted resonance produced in a bandpass filter of one duplexer, such as the receive bandpass filter **121**Rx of the duplexer **120**, may influence the bandpass characteristics of a bandpass filter of another duplexer, such as the receive bandpass filter **131**Rx of the duplexer **130**. Unwanted resonance produced in a bandpass filter of a duplexer, such as the receive bandpass filter **121**Rx of the duplexer **120**, may also influence the bandpass characteristics of another bandpass filter of the same duplexer, such as the transmit bandpass filter **121**Tx of the duplexer **120**. In this manner, when multiple bandpass filters are connected to the common terminal **60**, unwanted resonance produced in one bandpass filter may adversely influence the bandpass characteristics of another bandpass filter. Even in this case, the influence of the unwanted resonance can be lessened as a result of defining at least one SAW resonator in the bandpass filter having produced the unwanted resonance by multiple divided resonators.

Fifth Preferred Embodiment

A filter device according to a fifth preferred embodiment of the present invention will be described below with reference to FIG. **17**A. An explanation of the elements configured similarly to those of the filter device **20** of the first preferred embodiment (FIG. **1**) and those of the second preferred embodiment (FIG. **5**) will be omitted. While the filter device **20** according to the first preferred embodiment (FIG. **1**) is a bandpass filter, a filter device **20** according to the fifth preferred embodiment is a low pass filter.

FIG. **17**A is an equivalent circuit diagram of the filter device **20** according to the fifth preferred embodiment. The filter device **20** of the fifth preferred embodiment is preferably, for example, a n-type filter. An inductor **23** is connected in parallel with the SAW resonator **21** which connects the first terminal **25** and the second terminal **26**. A SAW resonator **21** is connected between the first terminal **25** and a ground, while another SAW resonator **21** is connected between the second terminal **26** and a ground. The SAW resonator **21** connected between the first terminal **25** and a ground includes two parallel-connected divided resonators **22**. As in the first preferred embodiment, the IDT pitch of one divided resonator **22** and that of the other divided resonator **22** are different from each other.

Advantages of the fifth preferred embodiment will be explained below. As in the first preferred embodiment, a drop in the insertion loss caused by ripples due to unwanted waves is regulated. Instead of the first bandpass filter **30** of the filter device **20** of the second preferred embodiment (FIG. **5**), the low pass filter of the fifth preferred embodiment may be used. In this case, it is possible to lessen the influence of ripples caused by the low pass filter on the bandpass characteristics of the second bandpass filter **40** or the third bandpass filter **50**.

A modified example of the fifth preferred embodiment will be described below with reference to FIG. **17**B.

FIG. **17**B is an equivalent circuit diagram of the filter device **20** according to the modified example of the fifth preferred embodiment. The filter device **20** of the modified example is a high pass filter.

The filter device **20** of the modified example is preferably, for example, a T-type filter. Two SAW resonators **21** are disposed in series with each other between the first and second terminals **25** and **26**. An inductor **23** and a SAW resonator **21** are interposed in series with each other between a ground and a node between the above-described two SAW resonators **21**. The SAW resonator **21** connected to the first terminal **25** includes two parallel-connected divided resonators **22**. As in the first preferred embodiment, the IDT pitch of one divided resonator **22** and that of the other divided resonator **22** are different from each other.

As in the modified example, a SAW resonator **21** included in a high pass filter may include two divided resonators **22**. In the modified example, as well as in the fifth preferred embodiment, the influence of ripples caused by the high pass filter on the bandpass characteristics of a bandpass filter can be reduced. As in the example shown in FIG. **3**A in the first preferred embodiment, it is possible to regulate a decrease in the attenuation characteristics caused by ripples occurring in the stopband of the high pass filter.

Other modified examples of the fifth preferred embodiment will be discussed below.

In the fifth preferred embodiment (FIG. **17**A), the SAW resonator **21** connected between the first terminal **25** and a ground includes two divided resonators **22**. Another SAW resonator **21** may include two divided resonators **22**. In the above-described modified example (FIG. **17**B), the SAW resonator **21** connected to the first terminal **25** includes two divided resonators **22**. Another SAW resonator **21** may include two divided resonators **22**.

Instead of the first bandpass filter **30** in the second preferred embodiment (FIG. **5**), a low pass filter is used in the fifth preferred embodiment (FIG. **17**A), and a high pass filter is used in the modified example of the fifth preferred embodiment. Instead of the first bandpass filter **30**, a band elimination filter may alternatively be used. In this case, one of multiple SAW resonators included in the band elimination filter includes a plurality of divided resonators.

The present invention is not limited to the above-described preferred embodiments. The configurations described in the different preferred embodiments may partially be replaced by or combined with each other. Similar advantages obtained by similar configurations in the plurality of preferred embodiments are not repeated in the individual preferred embodiments.

While preferred embodiments of the present invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing from the scope and spirit of the present invention. The scope of the present invention, therefore, is to be determined solely by the following claims.

What is claimed is:

1. A filter device comprising:

a common terminal;

first and second individual terminals;

a first filter connected between the common terminal and the first individual terminal;

a second filter connected between the common terminal and the second individual terminal, a pass band of the second filter being in a frequency range lower than a pass band of the first filter; wherein

the first filter includes a plurality of surface acoustic wave resonators, at least one of the plurality of surface acoustic wave resonators including a plurality of divided resonators connected in parallel with each other, each of the plurality of divided resonators including an interdigital transducer;

the plurality of divided resonators include at least two divided resonators, and among the at least two divided resonators, a pitch of the interdigital transducer of a divided resonator is different from a pitch of the interdigital transducer of another divided resonator; and

the interdigital transducers of the plurality of divided resonators are displaced from each other in a direction that is parallel or substantially parallel to an arrangement direction of electrode fingers of at least one of the at least two divided resonators and in a direction perpendicular or substantially perpendicular to the arrangement direction of the electrode fingers.

2. The filter device according to claim **1**, wherein at least a portion of a frequency range of a frequency which is about 0.7 times as high as a lower cutoff frequency of the pass band of the first filter to a frequency which is about 0.85 times as high as a higher cutoff frequency of the pass band of the first filter overlaps at least a portion of the pass band of the second filter.

3. The filter device according to claim 2, wherein

the first filter is a ladder filter including a plurality of parallel arms that branch off from a series arm connecting the common terminal and the first individual terminal;

among the plurality of surface acoustic wave resonators, at least one surface acoustic wave resonator is disposed between the common terminal and a first branch node of the series arm at which a parallel arm branches off from the series arm as seen from the common terminal; and

among the plurality of surface acoustic wave resonators, at least one of a surface acoustic wave resonator disposed between the common terminal and the first branch node, a surface acoustic wave resonator disposed between the first branch node and a second branch node at which a parallel arm branches off from the series arm as seen from the common terminal, and a surface acoustic wave resonator disposed on the parallel arm which branches off from the first branch node of the series arm includes the plurality of divided resonators.

4. The filter device according to claim 2, wherein

the first filter is a ladder filter including a plurality of parallel arms that branch off from a series arm connecting the common terminal and the first individual terminal;

none of the plurality of surface acoustic wave resonators are disposed between the common terminal and a first branch node at which a parallel arm branches off from the series arm as seen from the common terminal; and

among the plurality of surface acoustic wave resonators, at least one of a surface acoustic wave resonator disposed between the first branch node and a second branch node at which a parallel arm branches off from the series arm as seen from the common terminal, a surface acoustic wave resonator disposed between the second branch node and a third branch node at which a parallel arm branches off from the series arm as seen from the common terminal, a surface acoustic wave resonator disposed on the parallel arm which branches off from the first branch node of the series arm, and a surface acoustic wave resonator disposed on the parallel arm which branches off from the second branch node of the series arm includes the plurality of divided resonators.

5. The filter device according to claim 2, wherein (Pmax−Pmin)/Pa is about 0.7% or smaller, where Pa is an average of the pitches of the interdigital transducers of the plurality of divided resonators, and Pmax and Pmin are a maximum value and a minimum value, respectively, of the pitches of the interdigital transducers of the plurality of divided resonators.

6. The filter device according to claim 2, wherein

each of the plurality of divided resonators utilizes leaky waves or shear horizontal waves as main waves; and

a frequency of a ripple which occurs in bandpass characteristics of the first filter due to Rayleigh waves produced in the plurality of divided resonators is included in the pass band of the second filter.

7. The filter device according to claim 1, wherein

the first filter is a ladder filter including a plurality of parallel arms that branch off from a series arm connecting the common terminal and the first individual terminal;

among the plurality of surface acoustic wave resonators, at least one surface acoustic wave resonator is disposed between the common terminal and a first branch node of the series arm at which a parallel arm branches off from the series arm as seen from the common terminal; and

among the plurality of surface acoustic wave resonators, at least one of a surface acoustic wave resonator disposed between the common terminal and the first branch node, a surface acoustic wave resonator disposed between the first branch node and a second branch node at which a parallel arm branches off from the series arm as seen from the common terminal, and a surface acoustic wave resonator disposed on the parallel arm which branches off from the first branch node of the series arm includes the plurality of divided resonators.

8. The filter device according to claim 7, wherein

each of the plurality of divided resonators utilizes leaky waves or shear horizontal waves as main waves; and

a frequency of a ripple which occurs in bandpass characteristics of the first filter due to Rayleigh waves produced in the plurality of divided resonators is included in the pass band of the second filter.

9. The filter device according to claim 1, wherein

the first filter is a ladder filter including a plurality of parallel arms that branch off from a series arm connecting the common terminal and the first individual terminal;

none of the plurality of surface acoustic wave resonators are disposed between the common terminal and a first branch node at which a parallel arm branches off from the series arm as seen from the common terminal; and

among the plurality of surface acoustic wave resonators, at least one of a surface acoustic wave resonator disposed between the first branch node and a second branch node at which a parallel arm branches off from the series arm as seen from the common terminal, a surface acoustic wave resonator disposed between the second branch node and a third branch node at which a parallel arm branches off from the series arm as seen from the common terminal, a surface acoustic wave resonator disposed on the parallel arm which branches off from the first branch node of the series arm, and a surface acoustic wave resonator disposed on the parallel arm which branches off from the second branch node of the series arm includes the plurality of divided resonators.

10. The filter device according to claim 1, wherein (Pmax−Pmin)/Pa is about 0.7% or smaller, where Pa is an average of the pitches of the interdigital transducers of the plurality of divided resonators, and Pmax and Pmin are a maximum value and a minimum value, respectively, of the pitches of the interdigital transducers of the plurality of divided resonators.

11. The filter device according to claim 1, wherein

each of the plurality of divided resonators utilizes leaky waves or shear horizontal waves as main waves; and

a frequency of a ripple which occurs in bandpass characteristics of the first filter due to Rayleigh waves produced in the plurality of divided resonators is included in the pass band of the second filter.

12. The filter device according to claim 1, wherein Pd/Pa is about 0.02% to about 0.7%, where Pd is a different in the pitch of the interdigital transducer of the divided resonator and the pitch of the interdigital transducer of the another divided resonator, and Pa is an average of the pitches of the interdigital transducers of the divided resonator and the another divided resonator.

13. A filter device comprising:

a surface acoustic wave filter including a plurality of surface acoustic wave resonators; wherein

at least one of the plurality of surface acoustic wave resonators includes a plurality of divided resonators connected in parallel with each other;

each of the plurality of divided resonators includes an interdigital transducer, and among the plurality of divided resonators, a pitch of the interdigital transducer of a divided resonator is different from a pitch of the interdigital transducer of another divided resonator;

(Pmax−Pmin)/Pa is about 0.7% or smaller, where Pa is an average of the pitches of the interdigital transducers of the plurality of divided resonators, and Pmax and Pmin are a maximum value and a minimum value, respectively, of the pitches of the interdigital transducers of the plurality of divided resonators; and

the interdigital transducers of the plurality of divided resonators are displaced from each other in a direction that is parallel or substantially parallel to an arrangement direction of electrode fingers of at least one of the plurality of divided resonators and in a direction perpendicular or substantially perpendicular to the arrangement direction of the electrode fingers.

14. The filter device according to claim 13, wherein

the plurality of surface acoustic wave resonators define a ladder filter; and

the plurality of divided resonators are disposed on at least one of a series arm and a parallel arm of the ladder filter.

15. The filter device according to claim 14, wherein the ladder filter includes a plurality of the parallel arms.

16. The filter device according to claim 13, wherein Pd/Pa is about 0.02% to about 0.7%, where Pd is a different in the pitch of the interdigital transducer of the divided resonator and the pitch of the interdigital transducer of the another divided resonator, and Pa is an average of the pitches of the interdigital transducers of the divided resonator and the another divided resonator.

17. A filter device comprising:

a substrate made of a piezoelectric material; and

a plurality of surface acoustic wave resonators disposed on the substrate and connected with each other; wherein

at least one of the plurality of surface acoustic wave resonators includes a plurality of divided resonators connected in parallel with each other;

each of the plurality of divided resonators includes an interdigital transducer, and among the plurality of divided resonators, a pitch of the interdigital transducer of a divided resonator is different from a pitch of the interdigital transducer of another divided resonator;

among the plurality of divided resonators, an arrangement direction of electrode fingers of the interdigital transducer of a divided resonator is parallel or substantially parallel with an arrangement direction of electrode fingers of the interdigital transducer of another divided resonator; and

the interdigital transducers of the plurality of divided resonators are displaced from each other in a direction that is parallel or substantially parallel to the arrangement direction of the electrode fingers and in a direction perpendicular or substantially perpendicular to the arrangement direction of the electrode fingers.

18. The filter device according to claim 17, wherein

the plurality of surface acoustic wave resonators define a ladder filter; and

the plurality of divided resonators are disposed on at least one of a series arm and a parallel arm of the ladder filter.

19. The filter device according to claim 18, wherein the ladder filter includes a plurality of the parallel arms.

20. The filter device according to claim 17, wherein Pd/Pa is about 0.02% to about 0.7%, where Pd is a different in the pitch of the interdigital transducer of the divided resonator and the pitch of the interdigital transducer of the another divided resonator, and Pa is an average of the pitches of the interdigital transducers of the divided resonator and the another divided resonator.

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